MODERN ROADS

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PREFACE.

SOME excellent books have been written during the last few years, emanating from the United States, dealing from an American point of view with road construction and maintenance, but, owing to the Great War and other causes, very few have been written by authors in this country.

I have endeavoured in this book to deal with the subject of roads in as comprehensive a manner as is possible, bearing in mind the constant improvements in methods of modern road construction that are now taking place.

Criticisms will undoubtedly be forthcoming as to some of the statements, but it is only by "trial and error" that real progress is effected, and if this book becomes a medium by which such criticisms can be ventilated it will not have been written in vain.

It will be observed that no references are made to "costs". They have been purposely omitted in view of the constantly changing prices of materials. Any such reference could only have been misleading.

It will be observed also that there are very few illustrations or drawings. A book on roads does not lend itself to illustrations, and although some books on this subject are interlarded with photographs of roads in various stages of disrepair or of excellence, they are of little practical value, and I have therefore refrained from being tempted to adorn this book with these artistic embellishments.

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MODERN ROADS.

CHAPTER I.

INTRODUCTION.

It is not proposed in this book to trace the history of road construction since the days of the Romans, this has been done by many writers and would serve no useful purpose.

Recent History of Roads.—The real history of the modern road commences only about 20 years ago, although previous to this date many attempts had been made to improve on the specification for the construction of what are known as Water-bound Macadam Roads, which had been in vogue since the days of that great road engineer, Thomas Telford. The author had himself in the "early eighties" successfully treated the surfaces of gravel footpaths with ordinary coal tar and laid some considerable lengths of tarred macadam carriage ways with varying success. In his book, "The Municipal and Sanitary Engineer's Handbook," published in 1883, he gave a description of this method of road construction, and in the 3rd edition, published in 1889, he gave a complete specification of "tar macadam," the principles of which hold good to the present day.

Introduction of Self-propelled Traffic.—But it was not till about the year 1907 that public opinion was roused as to the condition of our roads, brought about by the ever-increasing self-propelled traffic upon them, a traffic which carried weights, and travelled at such speeds, as had never before been contemplated.

It was a complete, and almost sudden, traffic revolution.

Early Complaints of Motor Traffic.—The public Press was bombarded with letters from all classes of the community complaining of the excessive dust, and the destruction of the roads caused by the new traffic; they clamoured for remedies to mitigate the nuisance. This is now almost "ancient history," but from a perusal of the papers of that date, these complaints may be summarised as follows:—

(1) Excessive dust raised to great heights. This was mainly then assumed to be caused by the draught of air produced by the body of the car being so near the ground and the excessive speed of the car.

(2) The greater wear and attrition of the surface of the roads owing to these speeds, and the effect of the steel-studded tyres with which so many of the early cars were provided.

(3) The excessive noise of the horns, hooters, syrens, whistles, and exhausts.

(4) The "bullying aggressiveness" of the drivers of motors, who seemed to consider that the roads were made solely for their own particular benefit.[1]

(5) The great interference with the ordinary user of the roads, and the consequent necessity for widenings, and the improvement of dangerous corners.

As a specimen of the description of public correspondence at that time, the following extract from a letter written by a well-known public character to "The Times," of September 3, 1908, may be given:—

"Shall, or shall not, motor cars be allowed on public roads, or alternatively, shall any vehicle be allowed to exceed a speed of 10 miles an hour on a highway?"

Needless to say, this drastic proposal was not adopted, but the road engineers throughout the country at once set to work to meet the changed conditions of the traffic, with the result, that although self-propelled traffic has increased by leaps and bounds, we now hear very little indeed of any serious complaints.

Alleged Damage by Motor Omnibus.—But history often repeats itself, and, more recently, there has been an outcry as to the special damage caused to our roads by the introduction

[1] One complainant suggested that the name "chauffeur" should be changed to "show offer".

of the motor omnibus. This vehicle, with a loaded weight of about 6 tons proceeding at speeds of over 20 miles an hour, has, it is alleged, a disastrous effect on the surface of a road which has not been well constructed on up-to-date lines. Consequently this description of vehicle has been specially selected for the impost of a tax, when using certain roads, of no less than $\frac{1}{8}$th of a penny per mile run. Some of us may doubt the wisdom of imposing such a restriction on the free use of our public roads, and the justice of selecting any particular licensed vehicle for a special tax.

The Right of Public User of the Roads.—In this connection it is interesting to read the following extracts from the judgment of that great lawyer, Lord Justice Fletcher Moulton, in the Court of Appeal in the case of the Billericay Rural District Council and the Poplar Guardians, wherein he stated, *inter alia* :—

"(*a*) At the present day the essential characteristics of the law with regard to user of our roads is that every member of the public is entitled to use them properly as much as he needs.

"(*b*) The community have come definitely to the conclusion that absolute freedom of user coupled with communal upkeep of the roads is the wisest thing for the nation."

These unprejudiced words by so eminent a judge will commend themselves to posterity, and it is evident that the wise and large-minded policy to follow may be summed up in the axiom, "Roads must be adapted to the traffic and not the traffic to the roads".

Prompt Action by Road Engineers.—The road engineers throughout the civilised world were quick to realise this, as was evidenced at the first great International Road Congress held in Paris in 1909, when delegates to the number of about 2,000 attended and discussed the various problems which had arisen owing to the extraordinary changes which had occurred in road traffic.

The Road Board.—Another outcome of this great revolution in our traffic was the formation of the Road Board under powers conferred by the "Development and Road Improvement Funds Act, 1909".

Under Sec. 8 of that Act the powers of the Board were defined, *inter alia*, as follows:—

"(*a*) To make advances to County Councils and other highway authorities in respect of the construction of new roads or the improvement of existing roads.

"(*b*) To construct and maintain any new roads which appear to the Board to be required for facilitating road traffic."

The expression "improvement of roads" was defined as including road widening, cutting off corners where land is required for the purpose, the levelling of roads, treatment of roads to mitigate dust, "and the doing of any other work in respect of roads beyond ordinary repairs essential to placing a road in a proper state of repair".

Constitution of the Road Board.—The Road Board was constituted in the year 1909, and consisted of the following members:—

Sir George S. Gibb, Chairman.
The Rt. Hon. Lord Pirrie, K.P.
The Rt. Hon. Sir John H. A. Macdonald, K.C.B.
Lord St. Davids.
Sir Charles Rose, Bart., M.P.
Mr. W. Rees Jeffreys, Secretary.
Colonel R. E. Crompton, C.B., R.E., M.Inst.C.E., Consulting Engineer.

Appointment of a Special Advisory Committee.—In 1910 the Board appointed an "Advisory Engineering Committee," consisting of the following members:—

Mr. H. Percy Boulnois, M.Inst.C.E., Deputy Chief Engineering Inspector of the Local Government Board for England and Wales.
Mr. J. A. Brodie, M.Inst.C.E., City Engineer, Liverpool.
Mr. P. C. Cowan, B.Sc., M.Inst.C.E., Chief Engineering Inspector, Local Government Board for Ireland.
Mr. H. P. Maybury,[1] M.Inst.C.E., County Engineer of Kent.

[1] Now Brigadier-General Sir H. P. Maybury, C.B., K.C.M.G., the Chief Engineer and Manager of the Road Board.

Mr. J. Walker Smith, M.Inst.C.E., Chief Engineering Inspector, Local Government Board for Scotland.

Mr. John Willmot, F.S.I., County Surveyor, Warwickshire.

Duties of the Committee.—Their duties, as defined in the minutes of their appointment, were as follows :—

"(1) To act as an Advisory Committee in such questions as may, from time to time, be referred by the Board for advice.

"(2) To advise the Board as to any matters in regard to which, in the opinion of the Committee, it would be desirable for the Board to have information, or to take any action in order to promote or assist either general improvements or standardisation in methods or materials used in the construction or maintenance of roads, or in the collection and dissemination of information in regard to such matters or to road traffic statistics."

The Activities of the Committee.—Prior to the War this Committee met very frequently, and they travelled many miles in motor cars inspecting roads and works of road construction all over the country. They thus obtained a considerable amount of knowledge of what was going on and what was needed. They produced various standard specifications on the subject, some of which are either given or referred to in this book, and in many other ways they furthered the all-important question of the construction of good roads.

Dissolution of the Committee.—Owing to the changes now in contemplation by Parliament, for the formation of a Ministry of Ways and Communications, this Committee has been dissolved.

Funds of the Road Board.—The funds placed at the disposal of the Board for the above purposes consisted of the motor spirit duties and the carriage licence duties. These produced an income of about £1,160,000 per annum from the time of the formation of the Board up to the time of the Great War, when the whole of these funds were diverted to other Imperial purposes more directly associated with the War.

The Board's Circulars.—In July, 1910, the Road Board issued a circular to all the County Councils and other highway authorities throughout the United Kingdom which contained, *inter alia*, the following interesting remarks:—

"For the guidance of highway authorities who contemplate making application for advances, the Board desire it to be understood that, at the outset, applications should be confined to those of the most important and urgent nature, and that special consideration will be given to those in connection with proposals dealing with—

"(1) Reconstruction of important roads, the condition of which is exceptionally bad and cannot be improved without reconstruction.

"(2) Widening of important roads which are dangerously narrow.

"(3) Surfacing with granite, basalt, or other suitable material treated with tar or other bituminous compound by some approved method, main roads or important district roads which already have adequate foundations, especially those on or just beyond the outer fringe of large towns which have to carry a heavy traffic without aid from the rates of the towns served by the roads.

"(4) Opening out of dangerous corners and alteration of dangerous curves.

"(5) Alteration, where possible at reasonable cost, of steep and dangerous gradients.

"(6) Strengthening or reconstruction of weak bridges, which seriously limit the use for commercial transport of roads of first-class importance.

"(7) Construction of new bye-pass roads to avoid villages on main roads or important district roads where the conditions are exceptionally dangerous.

"(8) Acquisition in urgent cases where building is imminent of vacant land required for future widening of roads, especially in urban or suburban areas."

Large grants were made by the Board after the issue of this circular, and there can be no doubt that the formation of this Board was a step in the right direction, and stimulated work on the roads of this country to a remarkable degree.

The Board's First Report.—In their First Annual Report, issued on August 18, 1911, the Board stated:—

"In dealing with applications for grants for the improvement of road crusts, the Board decided to encourage the use of bituminous binding materials. They are advised by their Advisory Engineering Committee that it is essential in order to obtain strong and durable road surfaces which will bear modern traffic, that the old water-bound system of construction should be superseded by the use of some bituminous binding material on all important roads which have to carry heavy and fast traffic. Progress in this direction must be cautious and tentative, but there is a general consensus of opinion amongst road engineers that the adoption of bituminous treatment is advisable, and a fairly widespread desire on the part of local authorities to proceed in this direction.

"The Advisory Engineering Committee of the Board prepared a set of general directions and specifications relating to tar treatment, and these were published under the authority of the Board in April, 1911. It is believed that these specifications will be found to be of considerable assistance to local authorities."

This prophetic statement of the Board has been amply justified by the results, and the ordinary water-bound road is now giving way to roads constructed on lines which it will be the object of this book to describe.

Problems which Arose.—It was, of course, inevitable that, with this sudden alteration from what may be called "communal" to "State-aided" roads, there arose numerous problems which had to be faced, especially as to that of how the money grants were to be distributed. It was evident, for instance, that some discrimination should be made between road authorities who had persistently neglected the proper upkeep of their roads and those who required assistance for legitimate road improvements. There were other problems requiring adjustment which, perhaps, may be shortly summarised as follows:—

(1) Was it practical to classify the roads throughout the country on the basis of the amount of traffic they might be

called upon to carry, and to settle the description of improved construction of their surfaces to fairly meet each case?

(2) Could "tar spraying" be regarded as adding to the life of a road surface, or was it merely a dust palliative?

(3) Could any standard of maintenance be fixed for a road after it had been reconstructed or tar sprayed?

(4) On what basis should grants in aid be made, whether according to ascertained traffic, population, rateable value, condition of roads, standard of maintenance, or how?

(5) In what manner could traffic statistics be taken, and how could they be standardised.

These and other problems confronted the Board, and road surveyors were also asking that the Board should conduct laboratory and other tests as to the behaviour of road materials, and that the Board should, if possible, standardise and specify the various materials used in road construction, such as tar, bitumen, road metal, etc., and also that model specifications should be issued by the Board as a guide to modern methods of road construction.

All these points were carefully considered by the Board and their Advisory Engineering Committee, and every one of the points were dealt with in due course. Experiments were carried out, a complete laboratory installation was provided at the National Physical Laboratory, Teddington, trial sections of roads were laid, and specifications were issued dealing with "The Tar Treatment of Roads," "Water-bound Macadam Roads," and other useful information was, from time to time, issued.

Dissolution of the Road Board.—The Road Board was constituted at a critical period in the history of road making, and more than justified the expectations that were then formed as to what it might, and could, do towards an improvement in our roads.

It is to be regretted that, since the above words were written, it has been decided by Parliament to "disestablish" this most useful Board, and to substitute a "Ministry of Ways and Communications" to deal with the roads of this country, as well as Railways, Canals, Docks, Light Railways, and almost every known means of transport except "Flying". It is to be hoped that this new Department will thoroughly realise that, as a means of transport, our roads take the first place, as they are free from tolls, reach everywhere, and are subject to but very few restrictions.

Classification of Roads.—With regard to the proposal which was started by the Road Board to divide the whole of roads into classes on the basis of traffic, and was only stopped by the outbreak of War; this will be a gigantic task when we consider the following figures:—

In England and Wales alone, outside London and the County Boroughs, there are 27,879 miles of roads maintained by and at the cost of 61 County Councils. There are 111,884 miles of district roads maintained by and at the cost of 1,727 "district authorities" in urban and rural areas. A total of 139,763 miles. When we also consider that these roads are "managed" by 1,860 different "authorities" the task becomes even more difficult.[1]

Lack of Uniformity of Road Control.—One of the chief grievances brought forward by many people, when the "road crusade" was commenced in 1908, was the great want of more uniformity of control. Road users frequently complained that after passing over a stretch of fairly well-kept roads they suddenly plunged on to roads that were scarcely passable. It is interesting to note that within 15 miles of Charing Cross there are ninety different road authorities, and that there is a certain "main" road which passes through ten different road authorities in a length of 20 miles! This division of authority makes it almost impossible to standardise any description of road surface with any likelihood of its adoption, but at the same

[1] When we compare these lengths of roads with those in the United States of America the figures are rather staggering. From a recent report it appears that there are no less than 2,151,570 miles of public roads in America, giving 1 mile of road to every 35 inhabitants. The area of land taken up by these roads is estimated at 10½ million acres of a value of 70 million pounds. There is only 1 mile of railway to 10 miles of road, and the annual expenditure in this great length of road is £16,000,000, or say, only £8 per mile; this small expenditure can easily be accounted for when we realise that out of the 2,151,570 miles of road nearly 2,000,000 miles are only "earth roads," which require only about £1 per annum, per mile, to keep in repair.

time it is a matter of congratulation to find that on the whole, the roads of this country compare favourably with the roads of other countries where they are nationalised.

Suggestions for Classification of Roads.—In connection with the classification of roads some useful suggestions were made in a memorandum on the subject issued by the Highways Committee of the County Councils Association, which may briefly be summarised as follows:—

All Boroughs or Urban Districts should be responsible for all first-class roads within their areas, and all other first-class roads should vest in County Councils as first-class county roads. Half the cost of maintenance to be paid by the Exchequer and half by the County Councils. All second-class roads to be vested in the Borough or Urban District Councils, except any second-class roads which were main roads before the Act, of which the County Councils were to be allowed to retain control. The cost of maintenance to be divided as follows: one-quarter by the Exchequer, one-quarter by the County Council, and one-half by the Borough or Urban District Council.

The Treasury Departmental Committee on Local Taxation eventually issued the following recommendations which were adopted by the Government:—

(1) That the roads in administrative counties be classified by the Road Board into main roads, county roads, and district roads.

(2) That one-half of the cost of maintenance of such main roads and one-quarter of the cost of county roads be met by Exchequer grants.

(3) That the balance of the cost of main roads and one-quarter of the cost of county roads be borne by county funds, the remaining half of the cost of county roads being charged to the highway district responsible for maintaining the roads.

(4) That the roads in London and the County Boroughs be classified by the Road Board into main roads and streets, and that an Exchequer grant be paid in respect of main roads at the average rate per mile for the main roads in the urban portions of the adjacent administrative county or counties.

(5) That the necessary Parliamentary authority be obtained as soon as possible to enable the Road Board to commence a provisional classification of roads.

Road Board's Fourth Annual Report.—Before passing from the Road Board it is very interesting to note in their Fourth Annual Report, that from May, 1910, to March 31, 1914, the total grants made "for improvement of road crusts," amounted to £1,900,574, and £217,469 for widenings, improvement of corners, and curves, and road diversions. They say in their report that it is evident that "the most pressing and the most universal need is the strengthening and improvement of the crusts [which include foundations as well as surface coatings] of existing roads".

Estimated Cost of Re-surfacing Roads.—There is also another very interesting point which may be gathered by a simple dissection of the accounts, viz. that the improvements of the "crusts" of the road had been about £1,876 per mile. Assuming that the width of the carriage way averaged 15 ft., the cost per square yard has been about 4s. 3d. Now, as has been pointed out, there are 139,763 miles of roads in England and Wales alone, and if all the roads were dealt with at this figure the cost would reach the enormous total of 262 millions of money! It might be well if the general public, who are often too prone to find fault with our roads, could realise this gigantic figure![1]

The Dust Nuisance.—Referring again to the outcry which was raised in the public Press in 1908, which really marks the commencement of the history of modern roads, a few words upon dust, which was mainly the cause of the indictment at that time, may be of interest.

Road dust is mainly created by the attrition of the road surface and also by the spewing up of the earthy materials from below the surface, aptly termed, when in this condition, "dried mud". There is, in addition to this, the mud which is imported into the road from adjacent fields or roads by the

[1] This was written before the War and our ideas of gigantic figures have materially altered. It is acknowledged now that at least £300,000,000 are required "at once" for our roads!

wheels of vehicles, and also dust and debris blown on to the road from adjacent fields or premises. This description of mud, or dust, is mostly of a silicious character, but added to this are the droppings from horses and other animals using the road.

The Remedies.—The remedy for the first two causes of dust was the substitution of a bituminous binder for roads instead of the old method of binding the stones together with chippings and water, or even, in some cases, "dirt" and water, which could only be of a very unstable and temporary nature.

The remedy for the latter is, of course, proper scavenging or "slopping," as it is, of course, as impossible to obtain a perfectly dustless road as it would be to obtain a perfectly dustless house. The services of the scavenger are as necessary in the first case as those of the housemaid in the latter.

Effect of Motor Cars on Dust.—It is doubtful if the introduction of the self-propelled vehicle created, or manufactured, more dust than the ordinary horse-drawn traffic, but what it did do was to lift the dust from the surface and cast it to great heights in the air.

Various tests and experiments were made as to this, both in America by Mr. L. W. Page, Director of the United States Department of Roads, and also in this country by a Committee of the Royal Automobile Club and others. The result of these tests and trials conclusively proved that the dust raised by a motor car at ordinary speed is always, in the first instance, lifted from the road surface by the action of the wheels and tyres. The Royal Automobile Club Committee, in their report, published in October, 1908, state specifically: "In no case has the air current produced by the body of a car been found sufficient to move, or lift, the dust from a road. Cars with the very small body clearance of 6 inches from the road surface are found not to disturb or to raise any dust from a thick coating, if laid between cleanly swept wheel tracts up to speeds of 40 miles an hour."

Mr. Page's experiments showed that the dust was entirely raised by the back or driving wheels of the car, and that the front wheels, although perhaps slightly disturbing the dust, did not, as had been anticipated, create dust which would thus be brought into the vortex of air rushing under the body of the car and violently ejected at the back of the car.

Centrifugal Force of Wheels Rotating at Speed.—There can be but little doubt that with a motor car travelling at considerable speed, the effect of the rotating wheels would be to act as a brush on the surface of the road, to dislodge and pick up the particles of the dust, and to hurl them into the air. The tyre speed of a motor car travelling at the rate of only 20 miles an hour may be assumed at about 29 ft. a second, and the result of this centrifugal force is naturally to throw up the dust to a considerable height. This brushing action is, of course, accentuated when a car is travelling at great speed, as the driving wheels are rotating at greater speed than the car is travelling, with a consequent shear or brushing action on the surface of the road.

Dust Palliatives.—To obviate this dust nuisance, a great number of "dust palliatives" were patented and put on the market. Many of them were complete failures, and the best of them were mere palliatives and nothing more; they were not, and never could be, permanent cures.

It was not until tar painting or spraying the surface of the roads came into more universal adoption that the nuisance was permanently abated. This method, and also the complete alteration in methods of road construction, will be dealt with later in considerable detail.

Having thus far given a brief sketch of the modern history of road construction, it will be well to close this introduction with a few words as to the problems with which a highway engineer may be confronted.

Problems of Road Construction.—The whole question of road construction and maintenance has, within the last few years, altered to one of extreme complexity, and has emerged from a "rule of thumb" method to one of more scientific procedure.

There can be no doubt that the recent change in the traffic on our roads may eventually result in developments which we can yet hardly realise. The road of the future may be called upon to carry greater and greater weights at ever-increasing speeds, and engineering problems of considerable difficulty will have to be met and overcome. Already the changes have been so great in the last fifteen years that carriage ways constructed as they were at that time are already out of date, and more scientific methods are almost daily being introduced. We cannot stay the tide of increased and altered traffic, and it is evident that a considerable amount of scientific and practical knowledge will be required to cope with this novel evolution. Formerly the only persons interested in the upkeep of the roads [in addition to the surveyer responsible for this work], and the only persons who criticised the methods adopted for their construction and maintenance, were the road users, the ratepayers, and the "amateur experts". Now these ranks have been strengthened by many chemists and technical experts who are taking a keen interest in the "road question," as they no doubt see that there is a "future" for those who will examine this problem from the technical as well as from the practical side.

It may, of course, be truly said that laboratory experiments and technical calculations will not make good roads, as there are so many practical considerations which will upset such minute investigations. It may also be said that the majority of the roads in this country will bear favourable comparison with any in the world ; that the present road engineers have risen to the occasion, and have adopted modern methods and scientific means to overcome the great change that has occurred ; but it cannot be denied that the man who is equipped with a thorough scientific knowledge of his subject is better able to cope with the present-day traffic problems than one who is not so equipped.

Formation of a New Profession.—It would almost appear that another profession, that of the highway engineer, has sprung into existence. It has been stated that the highway engineer of the future will "require to have the engineer's knowledge of location and construction, the chemist's knowledge of chemical and physical analysis, and the geologist's knowledge of the formation of the crust of the earth and of the character and formation of its rocks ".

Points a Road Engineer Should Consider.—Take, for instance, a few of the points which should be considered before an engineer could advise as to the best method to be adopted for repairing or reconstructing an existing rural road. They may be summarised shortly as follows :—

(1) The description and amount of the traffic at present using the road, and what it may expect to be like at the end of, say, five years. This traffic should be carefully ascertained and reduced to a standard of tons per yard width per annum.

(2) The physical features of the road, whether open or shut in by trees and high hedges, its widths, gradients, and alignment.

(3) Whether it is properly drained or not, or is it waterlogged? and whether the sides or haunches are sufficiently supported.

(4) The geology of the district, not only for the purpose of ascertaining the character of the natural foundation, but also as to the possibility of securing local materials for its repair, or reconstruction.

(5) The meteorology of the district, the maximum and minimum rainfall, and the extreme ranges of temperature, the possibilities of severe frost, rainfall, or drought, etc.

(6) The strength and suitability of the artificial foundation, if any, or whether the accumulation of road metal is sufficiently deep and strong, and, at the same time, whether it is porous enough for drainage.

(7) A careful inspection of the neighbourhood to observe the class of inhabitants and their trades and any special local requirements as to traffic.

(8) Information as to the allowable rating of the district in order to ascertain its financial resources.

These and probably many more questions will arise before deciding on the proper method for dealing with the road in order to ensure that a mistake will not be made.

Then, having decided these points, the road engineer will have to make up his mind as to what extent the road requires reconstruction and how it is to be carried out, the drainage, the sub-crust, the strength crust, and finally the surface. Here he will be confronted with a large selection of different methods of construction from which he will have to make his choice, and he should be able then to judge, and only then, as to which form of construction is the best to meet the individual case.

Importance of Good Roads.—Never in the history of this country has the question of the need for good roads reached the importance that it has to-day. The enforced neglect of our roads for upwards of four years, owing to the War, and the fact of the State grants of money for use on the roads having been diverted to other Imperial needs, has left many of our roads in a deplorable condition. This has been accentuated by the military and other heavy traffic they have had to bear, and many millions of pounds will have to be expended in order to restore them to their normal condition.

Increase of Traffic.—The traffic also on the roads is bound to increase. The congestion on the railways, the release of thousands of lorries and other vehicles from military duty to civil work, the tendency of retail shops to supply their customers at ever-increasing distances, the desire to spread our populations towards the suburbs, the importance of the transport of produce and manufactures direct to the consumer with as little handling as possible, and many other causes are all tending towards such an increase of traffic on our roads which would have been felt to be impossible in the days of horse-drawn traffic. The advent of the self-propelled vehicle was a revolution in locomotion, the results of which must be far-reaching in the effect on our roads unless they are so constructed that they will withstand the enormously increased traffic which they will be called upon to bear.

Increased Traffic must be Met.—It will be impossible to keep this traffic off our roads by the imposition of a mileage tax on certain vehicles, which really have as much right to the use of the king's highway as any other vehicle, be it a motor omnibus or a costermonger's donkey cart; the flowing tide cannot be kept back by Mrs. Partington s mop, or even a

King Canute, and any onerous restrictions on legitimate traffic can only result in the crippling and retardation of industry.

The "people" are clamouring for cheap means of public conveyance on the roads so that they may be housed in the country and work in the towns, and any interference with these facilities will seriously handicap the present developments of garden cities and town planning.

The question of the free use of our roads must be dealt with on the broadest possible principles, nor must legislation act as it did in the early days of self-propelled traffic, viz. insist on a man walking in front of every vehicle with a red flag! This "put the clock back" about a couple of years, and should be a warning at the present time to those who are unable to grasp the evolution of the world, not only in means of communication, but in almost everything else.

CHAPTER II.

TRAFFIC.

BEFORE considering the question as to the proper or best material with which to re-surface an existing carriage way, or how to construct a new road, it is of the utmost importance to know the weight and description of the traffic it will have to bear.

Severity of Traffic.—The "severity" of traffic which a road has to bear is, however, a rather difficult matter to arrive at with any degree of accuracy, as this severity cannot be quite the sum total of the weights of the traffic because different forms of traffic have different effects on the surface of a road. For instance, a certain number of traction engines may give the same weight of traffic as a larger number of light motor cars, but the damaging effect of the traction engines might be proportionately very much greater on certain classes of road surface than a much larger number of light motor cars. The question of speed of the vehicles is also to be considered, so that the deductions to be drawn from traffic observations are not all that is necessary in considering this traffic problem.

There is also the difficulty of differentiating between what may be called "the up and down" traffic, as it frequently happens that all the heavily weighted traffic is on one side of the road and the "return" empty traffic is on the other side. As an instance of this the following table is given to show the difference in wear after a period of years of granite setts in certain streets in Liverpool due to this cause:—

	East Side.	Centre.	West Side.
Street A	Nil	$\frac{1}{8}$ in. to $\frac{1}{4}$ in.	$\frac{1}{2}$ in.
,, B	$\frac{3}{8}$ in.	$\frac{3}{8}$ in.	$\frac{3}{4}$,,
,, C	$\frac{1}{4}$,,	Nil	$\frac{3}{4}$,,

In the above cases the weight of the traffic on the West side may be assumed as having been about ⅓rd heavier than that on the East side, so that if "distributed" traffic was to be taken as the criterion it would not fairly represent the actual "severity" of the traffic on one portion of the surface of the street.

Action by the Road Board.—The Road Board realised the importance of the question of traffic, as shown by the fact that before attempting to enter upon the colossal task of arranging the three groups into which all the roads of the United Kingdom were to be classified, they asked for careful statistics to be taken on a very large number of roads throughout the country. They issued forms to county and borough surveyors and to others which were to be filled in and returned to the Board when completed.

Statistics as to Traffic.—The "day" returns contained spaces for the name of the county or district, the exact spot on which the observations were made, with the width of the metalled carriage way, the footpaths [if any], and the roadside margins, the date on which the observations were taken, and the name of the observer; the condition of the road, the weather, and the hours of the day or night during which the observations were taken. There was also a very complete classification of the nature of the vehicles using the carriage way with the following weights for each vehicle, etc.: ordinary bicycles, ·09 of a ton; motor cycles, 0·13; motor cars [including motor cabs, etc.], 1·6; motor vans [covered in], 2·5; motor omnibuses, 6·0; motor lorries [rubber tyres], 6·0; trailers to rubber tyred lorries, 5·0; motor lorries [steel tyres], 10·0; trailers to motor lorries [steel tyres], 5·0; light tractors, 5; traction engines, 12; trailers to traction engines, 8·0.

With regard to horse traffic the following weights were given: light vehicles [1 horse], ·40 of a ton; light vehicles [2 or more horses], ·60; heavy vehicles [1 horse], 1·25; heavy vehicles [2 or more horses], 2·5; omnibuses [2 or more horses], 3·0; horses [led or ridden], ·50; cattle, ·30; sheep and pigs, ·10. The horses drawing vehicles to be calculated from the number of vehicles of the class and each horse to be calculated at a further ·50 of a ton.

Standardisation of Traffic.—From the knowledge gained by these statistics, reduced to tons weight carried per yard of width of carriage way per annum, the Board would thus have been able to standardise the traffic for any road. If possible some standard should be arrived at in order that the behaviour of any road could be compared to the traffic which it ought to bear in relation to its first cost of construction and subsequent maintenance, reduced to say one-hundredth of a penny per ton mile of traffic. This method of tons per yard width per annum is much more satisfactory than that hitherto pertaining in France where the calculation is made from the number of "collars"; a vague and unsatisfactory method as the weights are not given. Up to quite lately, also in England, the method has been to classify traffic under the following headings:—

"Light Traffic" has been held to mean about 70 vehicles a day, including an occasional traction engine or heavy motor.

"Medium Traffic" from 70 to 250 vehicles a day, including not more than 5 per cent. of traction engines or heavy motors.

"Heavy Traffic" from 250 to 600 vehicles a day, of which 5 to 10 per cent. consists of traction engines or heavy motors.

"Very Heavy Traffic," which is anything exceeding that coming under the head of "Heavy Traffic". This, of course, may be a sort of "rough and ready" guide as to the amount of traffic, but it is not based on the same scientific lines as those which were proposed by the Road Board.

Blackpool Adaptation of Severity of Traffic.—With regard to the manner in which roads are dealt with under an ascertained traffic, the late Mr. J. S. Brodie, M.Inst.C.E., the then Surveyor of Blackpool, gives the following interesting details of how he then dealt with the roads in Blackpool[1]:—

(1) For streets of 200,000 tons per yard width per annum, he paved with 6 ins. granite setts on 7 ins. of Portland cement concrete. [He gave the cost at about 12s. per square yard.]

(2) For first-class "shop streets" of 100,000 tons per yard width per annum, he paved with 6 ins. hardwood blocks on

[1] *Vide* "Practical Road Engineering," published by St. Bride's Press, Ltd., 24 Bride Lane, London, E.C.

6 ins. of Portland cement concrete. [Cost about 13s. per square yard.]

(3) For residential streets with light traffic of 20,000 tons per yard width per annum, he put a foundation or "bottoming" of hand-packed rubble 8 ins. in depth, covered with 5 ins. of tar macadam. [Cost about 4s. 9d. per square yard.]

(4) For ordinary residential streets with a light traffic of 5,000 tons per yard width per annum he put a similar foundation to that in No. 3, but only 7 ins. in depth, covered with 2½ ins. gauge of water-bound granite macadam of a consolidated depth of 5 ins., "blinded" with fine granite chippings. [Cost about 3s. 9d. per square yard.]

(5) For "back" or secondary access streets, which, owing to their narrow width, had a traffic of 60,000 tons per yard width per annum, he put a foundation similar to that in No. 4, paved with Haslingden [grit] setts 4 ins. to 6 ins. deep. The camber of these narrow streets was concave, with a channel in the centre. [Cost about 6s. 6d. per square yard.][1]

American Engineer's View of the Importance of a Study of Traffic.—On the importance of this question of traffic I cannot do better than quote the opinion of a well-known American road engineer, expressed at a meeting of the American Society of Engineers, so long ago as January, 1911, as follows:—

"It is quite evident that the selection of a suitable type of road for any locality should be governed largely by the volume and character of traffic to which the road will be subjected, and yet but little attention is commonly given to this matter. Attention is rarely given to more than the general nature of the traffic, i.e. whether it is heavy or light, and whether it consists mainly of motor vehicles or horse-drawn traffic. What is considered as heavy traffic for one locality may be considered as light for another, and, therefore, it would seem to be most important that a detailed record be made of both the character and the volume of traffic for each individual road of importance."

[1] These prices are now of no value, as the enormous increase since the War in wages, haulage, and material has completely changed all pre-War estimates.

Transition State of Traffic.—With reference to the traffic on existing roads, we are at present, and for some considerable time will be, in a transition stage, as the road surface has to be adapted for horse traffic as well as self-propelled traffic, and these have conflicting interests in the following respects:—

(1) An impervious surface may, under certain climatic conditions, become slippery, which may be dangerous for horses, whereas a self-propelled vehicle is not so seriously affected.

(2) A steep gradient is not of so much importance to a self-propelled vehicle as to a horse-drawn vehicle.

(3) Sharp corners are more dangerous for self-propelled vehicles than to horse-drawn vehicles.

Difficulties of the Highway Engineer.—Unlike the "Permanent Way" engineer of a railway, the road engineer has no control whatever on the weights and speeds of the vehicles which use his roads, and, in many cases, the description of vehicle using a road has a most damaging effect on it.

Suggested Tax on Vehicles.—It has more than once been suggested that all mechanically propelled vehicles should be taxed in order to pay for this damage, but the unfairness of confining taxation to only one class of vehicle is obvious, and could only have the effect of retarding the progress of modern development, and would tend to cripple the industries of the country.

In spite of any legislation that may be imposed, the mechanically driven vehicle has come to stay, and no one can foretell as to what weights, or at what speeds, the traffic of the future will develop.

It is evident, in this connection, that the highway engineer will have to make his roads suitable for the altered conditions of traffic, whilst, on the other hand, the road user should assist by endeavouring to take all the care possible, so as not to unnecessarily injure the surface of the roads.

Effect of Wheels on Roads.—It has been frequently urged that wheels of larger diameter should be used for the heavier class of motor traction than those now pertaining, viz. 41 ins. The effect of steel wheels of this diameter are often disastrous to a road, and it would appear that an increase in diameter is desirable. In connection with this, it is interesting to note that, in 1904, when the Heavy Motor Car Order, 1904, was being considered, the Local Government Board issued a Memorandum with regard to the minimum width required for the tyre of a wheel, having regard to the diameter of the wheel and the weight on the axle of that wheel. No less than fifteen examples were given of wheels, ranging between 2 ft. diameter and 5 ft. 6 ins. diameter. The following example of a wheel 2 ft. 6 ins. is given as an example :—

DIAMETER OF WHEEL—2 FEET 6 INCHES.

Axle Weight.						Width of Tyre.
	Tons.	Cwts.		Tons.	Cwts.	Inches.
			Not exceeding	3	5	5
Exceeding .	3	5	but not exceeding .	3	11½	5½
,, .	3	11½	,, ,, .	3	18	6
,, .	3	18	,, ,, .	4	4½	6½
,, .	4	4½	,, ,, .	4	11	7
,, .	4	11	,, ,, .	4	17½	7½
,, .	4	17½	,, ,, .	5	4	8
,, .	5	4	,, ,, .	5	10½	8½
,, .	5	10½	,, ,, .	5	17	9
,, .	5	17	,, ,, .	6	3½	9½
,, .	6	3½	,, ,, .	6	10	10
,, .	6	10	,, ,, .	6	16½	10½
,, .	6	16½	,, ,, .	7	3	11
,, .	7	3	,, ,, .	7	9½	11½
,, .	7	9½	,, ,, .	7	16	12
,, .	7	16	,, ,, .	8	0	12½

The "rule" under which the above table was prepared is as follows :—

The "standard" diameter was taken at 3 ft. and the width of tyre not less than ½ in. for every 7½ cwts., or fraction of 7½ cwts., of the certified gross weight to be carried on the axle to which the wheel is attached. If the wheel exceeds 3 ft. diameter the same rule applies, but with a proportionate increase above the 7½ cwts., in the ratio of 1 cwt. for every 12 ins. increase in the diameter of the wheel. For a wheel of less diameter than 3 ft. a proportionate decrease of the weight of 7½ cwts. in the ratio of 2 cwts. for every 12 ins. decrease in the diameter of the wheel. In no case was the width of tyre to be less than 5 ins.

These regulations were adopted in the Heavy Motor Car Order, 1904.

How to Ascertain Load Weights.—It is of course difficult in practice to be quite sure that these "authorised" weights are not exceeded, and the well-known weighing machine specialists, Messrs. W. & T. Avery of Birmingham, about the year 1911, constructed an "Axle Weight Ascertainer". They suggested that permanent concrete foundations should be constructed in suitable positions on the main roads of any district to take the machine as occasion required. The machine consists of two portable 6 ton weighing machines, the gross weight of which is about 2 cwts.; these, they stated, could be erected by one man in 3 hours at any time when and where required. The weigh bridges are placed in tandem so that the vehicle can be easily run on to the platforms and the weights on each axle are taken and registered and printed on two tickets. If either axle weight exceeds 8 tons the vehicle is being run illegally, and the owner can be proceeded against under the Order, and as penalties are attached, it is suggested that if owners of vehicles were aware that these platforms existed in any district they would be extra careful not to run any risks, and consequently the excessive damage to the roads caused by these illegally heavy vehicles would be saved.

Damage by Heavy Loads.—There can be no doubt that the greater part of the damage done to roads is caused by these very heavily loaded motor vehicles and their trailers. Mr. Harold Collins, A.M.Inst.C.E., the Deputy City Engineer of Norwich, in a paper which he read at a meeting of the Institution of Municipal and County Engineers, at Great Yarmouth in 1913, said, "he had personal knowledge of steam waggons with a loaded rear axle weight of over 10 tons with a wheel diameter of less than 3 ft. 6 ins. and tyres of 12 ins. width".

In the evidence given by Mr. R. J. Thomas, M.Inst.C.E., the County Surveyor of Buckinghamshire, before the Departmental Committee of the Local Government Board in 1918,[1] he put in the following table of the "indicated" and actual weights of four road locomotives which he had personally weighed:—

	Indicated Weights and upon which Licences were paid.			Actual Weights borne by Roads.				Excess.
	Tons	Cwts.	Qrs.	Tons	Cwts.	Qrs.	Lbs.	Per cent.
Case A 15	10	0	0	14	3	0	14	41
,, B 29	12	15	0	14	7	3	0	12
,, C 47	14	0	0	15	0	1	0	7
,, D 52	13	17	3	17	11	2	14	26½

Mr. Thomas and other witnesses pointed out to this Committee the damage done by these heavy vehicles with wheels shod with iron or steel tyres.

No doubt the order is a dead letter in many parts of the country, and the scheme for movable weigh bridges appears to have considerable merits.

The Motor Omnibus.—With regard to the motor omnibus, which is also said to be extremely detrimental to the surfaces of some descriptions of road surfaces, Mr. Wakelam, M.Inst.C.E., the County Surveyor of Middlesex, in a paper read by him at the annual meeting of the Institute of Municipal and County Engineers, at Great Yarmouth in 1913, said:—

"From observations and records it would appear that the extended use of motor omnibuses, weighing about 6 tons laden, is the chief cause of damage which is now being experienced, and to obviate which, as much as possible, it is fast becoming imperative that a road surfacing material other than water-bound metalling should be employed," and in 1914 Mr. Wakelam backed up this opinion by inducing a Committee of the House of Commons to insert in the Bill authorising the construction of the Great West Road out of London,

[1] *Vide* "Report of the Departmental Committee appointed by the President of the Local Government Board to consider the law and regulations relating to the construction and use of road locomotives and heavy motor cars in Great Britain," Part II, Minutes of Evidence, etc.

a clause whereby a tax could be imposed on all motor omnibuses using this road, when constructed, of no less a sum than $\frac{3}{8}$ths of a penny per ton mile. That this tax, if imposed, would go a long way towards the cost of upkeep of this road is evident, when we find from a paper read before the Institution of Civil Engineers [Session 1913-14] by Mr. Thomas Clarkson, M.Inst.C.E., that he gave a table showing that, whereas in the year 1905 there were only 200 motor omnibuses in the metropolis, there were 3,400 of these vehicles at the end of the year 1913.

Scientific View of Effects of Traffic.—Mr. H. R. A. Mallock, F.R.S., in his well-known paper, read before the Institution of Civil Engineers in 1909, on the "Construction and Wear of Roads," dealt exhaustively and scientifically on this question of traffic on our roads, and pointed out, *inter alia*, that the intensity of pressure caused by traffic becomes greater as the surface is approached, and that consequently the surface should be harder than the lower levels, or that it should have a greater elastic limit, and that too rigid a foundation may cause the surface to break up. He pointed out that, if a load is placed on a flat surface of a thick elastic solid, the surface is depressed and takes a hyperbolic form, the displacement at any part being inversely proportional to its distance from the load. He gave results of experiments showing that the effect of the mean pressure of a solid india-rubber tyre was about $\frac{1}{12}$th part of the mean pressure of an iron tyre. With pneumatic tyres the effect of the pressure was reduced to only about $\frac{1}{25}$th part of that of an iron tyre.

Summary of Effect of Self-propelled Traffic on Roads.—The above is a very scientific description of the effect of weight upon the road, but the following may be taken as a short summary of the effects of traffic upon a carriage way under the new conditions of mechanical propulsion:—

(1) Abnormal crushing of the material of which the surface of a carriage way is formed, due to increased weights and higher speeds. It is well known that the dynamic shock of a propelled vehicle is greatly increased by the speed at which the vehicle is travelling.

(2) Greatly increased amount of traffic owing to the longer distances which can now be covered.

(3) Disintegration of the surface of the carriage way and consequent "pitting," mainly caused by the "brushing" action of the pneumatic-tyred wheels when travelling at high speed, changing speed, and starting.

(4) The formation of longitudinal ruts, or tracks, due to the tendency of all self-propelled traffic to keep in the centre of the carriage way: an obvious necessity for fast traffic to lessen the chance of accident from other vehicles suddenly emerging on the road from side roads, or concealed gates, etc.

(5) The difference between "propulsion" and "draft," for whereas the latter is merely a sort of rolling action the former is a veritable push on the road in a direction directly opposite to that in which the vehicle is travelling.

(6) The greater shaking, or vibration, produced by self-propelled traffic, much accentuated by weight and speed, which causes inter-attrition of the stones or materials with which the carriage way is constructed. This shaking is augmented by a "bounding" action of the vehicle which did not occur so violently in the days of horse-drawn traffic.

This latter effect is, of course, much reduced by the introduction of pneumatic tyres, special springs, and other devices, and it is claimed that wire-spoked wheels not only lessen the weight of a vehicle, but also that, being more elastic, the shock or bump is thereby lessened.

Prevention of Shock.—Many devices have been tried to lessen this shock, the most ingenious of which was the "shock-shifter hub" introduced about eight years ago, and was fitted, experimentally, on some omnibuses running in the metropolis. This contrivance consisted of a special hub [see Fig. 1] which surrounded the axle with a number of loosely packed superimposed steel balls which filled the hub. It was claimed for this invention that "the weight of the vehicle itself causes centrifugal action among these [the steel balls], making a 'clean cut' of vibration away from the axle, and, strange fact, actually utilising the road shock, to a large extent, in propulsive effort, as is proved by a saving of 12½ per cent. in petrol, 2 per cent. in lubricants, over 20 per cent. in gear oil, and 6 per cent. in grease, certified by the London General Omnibus Company. At the same time, the wheel is maintained in true rolling contact on the ground. Mark that important fact. 'Whatever reduces shock to the road also reduces the reaction on the road, which is the main cause of road wear,' is the dictum of our most eminent practical authority."[1]

The invention was ingenious, although it failed as not

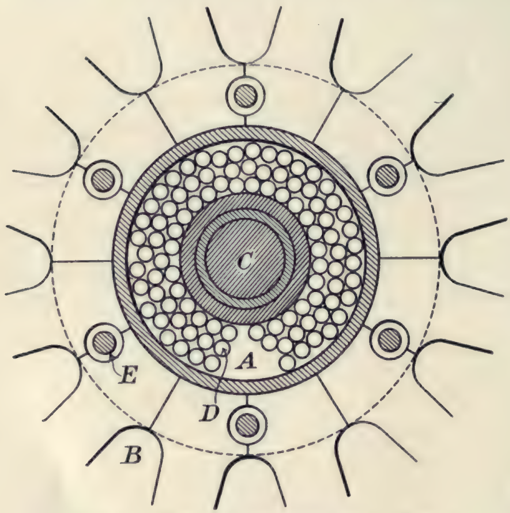


FIG. 1.—THE "SHOCK-SHIFTER" HUB.

A—Hub loosely filled with steel balls. B—Spoke communicating road shock. C—The axle. D—Point of impact of road shock on steel balls which absorb shock and are forced across vacant space A.

(Space A is exaggerated to illustrate the involved principle.)

giving a true centre for the axle, and for other reasons. Attention has been called to it merely to show that something of the kind would be a great boon to both road users and road makers if it could be ensured to be effective.

Professor Hele-Shaw on Shock.—On this question of shock Professor H. S. Hele-Shaw, LL.D., F.R.S., etc., gave a paper to the Institution of Mechanical Engineers a few years ago, in which he dealt with this question in an exhaustive

[1] From "The Surveyor and Municipal Engineer" of July 24, 1914.

manner, and, amongst other things, clearly showed that the bump or shock was greatly increased with an iron-tyred vehicle over that which was fitted with pneumatic tyres, and he showed this effect by the following simple diagram :—

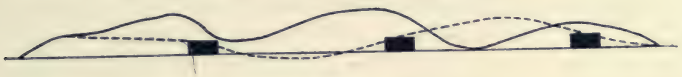


FIG. 2.

Track of iron tyre marked in strong black line.
,, ,, pneumatic tyre marked in dotted black line.
The black " squares " represent the " obstacles " over which the cars were driven.

It naturally follows that uneveness of a road surface increases the shock or dynamic effect of impact, so that, when this begins, the damage to the road increases in an almost geometrical ratio.

Summary of Damage Caused by Self-propelled Traffic.—To sum up the various statements which have from time to time been made as to the damage caused to roads since the introduction of mechanically driven vehicles, they may be shortly stated as follows :—

(1) Crushing due to excessive weight and insufficient area of the contact surface.

(2) Slip, or brushing action, due to imperfect adhesion.

(3) Suction on the road surface.

(4) Horizontal rotary movement due to steering or turning.

(5) Bouncing, or bounding, of the vehicle.

(6) Tracking due to tendency to keep motors in centre of road.

(7) Increase of traffic due to longer distances that can be travelled.

With regard to crushing, Mr. Mackenzie gives the following areas of pressure by various types of pneumatic rubber-tyred wheels as follows :—

Plain tread area	= 18·8 ins.
Notched tread area	= 17·5 ,,
Palmer ,, ,,	= 11·2 ,,
Studded ,, ,,	= 4·6 ,,

Wheel Diameter.—With regard to diameter of wheels, Colonel Crompton, C.B., the well-known advocate of large diameter wheels, says that the advantage of large diameter is, *inter alia*, that an 8 ft. diameter wheel, on a yielding surface, only has to climb up a gradient of 1 in 20, whereas a wheel of 2 ft. diameter has to climb up a hill of 1 in 10.

It is more than evident then, that the interests of both road makers and road users are closely bound together, and this unity is more than ever desirable since the introduction of self-propelled traffic.

Congestion of Traffic.—With regard to the general question of traffic and the recent endeavours to formulate rules and regulations for the avoidance of congestion, it is interesting to note that, in February, 1913, a large conference was held of road users and others to consider this question. Sir George Gibb, the Chairman of the Road Board, presided, and a committee was eventually appointed to consider the question and to report. This report was duly presented, and is appended [see Appendix A]. Nearly all the points were most carefully considered, and if some such regulations could be formulated they would no doubt lead to a partial mitigation of the present traffic evils.

The Royal Automobile Club also proposed a series of suggested traffic rules which are also given in the appendix [see Appendix B].

Proper Widths of Carriage Ways.—In connection also with the question of traffic, consideration should be given as to the proper widths for roads and streets when considered in the light of traffic requirements only.

At the First International Road Congress held in Paris in 1908, the following resolution was passed: "There should be but one roadway for every kind of vehicle proportional to the intensity of traffic, 19 ft. 8 ins. [6 metres] wide at least, except in the exceptional cases of broad pleasure avenues where several separate roadways are to be recommended".

Model Bye-laws.—There was little or no discussion on this resolution, and it is doubtful if it meets the requirements in this country, and it certainly does not comply with the model bye-laws issued by the Local Government Board, which say, *inter alia*:—

"Every person who shall lay out a new street which shall be intended for use as a carriage way shall so lay out such street that the width thereof shall be 36 ft. at the least . . . he shall construct on each side of such street a footway of a width not less than one-sixth of the entire width of such street."

It will thus be seen that under this bye-law the carriage way could not be less than 24 ft. wide with a footway on each side of 6 ft. in width.

Suggested Methods for Ascertaining the Best Widths.—How these widths, now completely out of date and obsolete, were arrived at it is not possible to say, but it may be assumed that ordinary horse-drawn vehicles had been found by experience to be able to pass each other safely, at some speed, in a width of 8 ft. and that pedestrians required 2 ft. This would give three vehicles for the carriage way and three pedestrians for the footway. With regard to this width of footway, it is doubtful if it is sufficient. Soldiers when marching in line are allowed a width of 2 ft. 6 ins. each and when marching in fours 2 ft. 3 ins. each. If this width is required for trained men, surely the civilian requires more space than 2 ft. It must not, however, be lost sight of that the pedestrian nearest the kerb allows his shoulders to project into the carriage way so that the width may really be sufficient. With regard to the width of the carriage way, there can be no doubt that when fixed for horse-drawn traffic it was not far wrong, as carriages and tradesmen's carts were not wider than from 5 to 6 ft., but the introduction of self-propelled traffic has considerably altered these widths as the following table will show:—

TABLE OF WIDTHS OF SUNDRY VEHICLES.

Furniture van	7 ft. 2 ins. to 7 ft. 6 ins.
Horse omnibus	7 ,, 0 ,, ,, 7 ,, 2 ,,
Motor omnibus	7 ,, 2 ,, ,, 7 ,, 6 ,,
Private motor car	6 ,, 6 ,, ,, 6 ,, 8 ,,
Taxi cab	5 ,, 6 ,, ,, 5 ,, 9 ,,
Trolley	7 ,, 6 ,, ,, 8 ,, 0 ,,

Although no doubt a self-propelled vehicle can, in the hands of a skilful driver, be steered better than a horse-drawn vehicle, it is evident that the multiple of 8 ft. can no longer be considered safe, and that probably 10 ft. would be none too much.

Speaking generally as to the total widths of roads, the following opinions by various well-known engineers may be of interest:—

Various Opinions as to Widths of Roads.—The late Mr. Gordon, when Surveyor of Leicester, at one of the meetings of the Institute of Municipal and County Engineers, held a long time ago, said that "he always devoted three-fifths to the carriage way and the remainder to the footways". This appears to be a better proportion than the present accepted proportion of two-thirds and one-third.

Mr. P. C. Cowan, the Chief Engineering Inspector of the Local Government Board for Ireland, in a paper read before the Second Irish Road Congress in 1911, said, "the width of the carriage way should be from 12 to 16 ft. in country roads and at least 30 ft. on roads of importance near towns". He also expressed the opinion that the minimum width between fences should never be less than 30 ft. in new roads, with a travelling way of 15 ft. between the margins. In France a width of about 16 ft. 6 ins. is usually devoted to the carriage way.

In America it is stated that 12 ft. allows two vehicles to pass each other, but that 15 ft. allows more space for comfortable travelling for motor vehicles. Verges or margins are recommended whereon a "team" can stand whilst two vehicles are passing each other. If the carriage way of such a road is too narrow the edges are liable to be sheared off by the traffic. In a more recent report issued by the American Society of Civil Engineers, it is stated: "Where motor traffic forms a considerable proportion of the total traffic . . . the unit width of traffic lines should be considered as 9 or 10 ft. instead of 7 or 8 ft. as heretofore, because of the greater clearance required for the safe passing of the units of such traffic".

Mr. Austin B. Fletcher of the Office of Public Roads, Washington, U.S.A., is of the opinion in a paper he wrote on "The Construction of Macadam Roads," that the carriage way need not be more than from 12 to 15 ft. in width as 12 ft. allows two vehicles to pass each other safely, but admits that more is required for motor cars. In 1890 the "Engineering Record of New York" gave prizes for essays on road making, and a committee of expert road engineers was formed to go through these essays and to award the prizes; in their notes on the essays they said, "a road should not be less than 16 ft. except where traffic is very slow when 12 ft. may answer".

It is interesting to note that all the authors of the essays differed as to what should be the best width, and one of them says, "a well-kept narrow road where width is sufficient for traffic is much better than a broad one with no greater amount expended for repairs".

Roads may be too Wide.—There is a good deal of truth in these latter remarks, for if the carriage way is too wide it may be neglected and often looks disproportionate to the width of the footways which spoils its appearance. A carriage way costs more to maintain than the footways; it has to be watered and scavengered, it creates more dust and mud. A carriage way that is too wide may lead to very straggling traffic, and refuges have to be constructed to guide the traffic, and also for the convenience and safety of the pedestrian public. If there is not much traffic a wide carriage way has a rather mournful and deserted appearance; it is well known, moreover, that for "shopping" purposes the narrow streets of a town are, as a rule, the more popular and the shops command higher rents.

Widths Require Careful Consideration.—It is evident, from what has thus been stated, that the proper widths of carriage ways and the proportion between carriage ways and footways require very careful consideration, and still more so in view of the possibilities that arise under the Housing, Town Planning, etc, Act of 1909, and the Development and Roads Improvement Fund Act of 1909, under which Acts the planning of new streets, avenues, boulevards, and the like, will have to be seriously contemplated.[1] It is impossible to lay down any

[1] It is interesting to observe that whilst the Ministry of Ways and Communications Bill was being considered by Parliament, Mr. Rees Jeffreys, the late

hard and fast lines as to the proper widths of roads and streets, each case must be carefully considered under the heads which have been discussed in the foregoing pages. Whilst, on the one hand, it would be a mistake to be bound by custom and convention, on the other hand it would be imprudent to make too large a provision for a traffic which may never arrive. The points for consideration, with regard to this portion of the chapter on "Traffic," may be summarised as follows :—

(1) What should be the total width of the carriage way to carry comfortably the traffic which it will be called upon to bear?

(2) What are the widths of these vehicles, and what space should be allowed so that they may safely pass each other at speed?

(3) What is the proper proportion between the carriage way and the footway, having regard to appearance, pedestrian traffic, first cost of construction, and subsequent maintenance?

Conferences on Arterial Roads.—Before concluding this portion of the chapter on "Traffic," so far as it concerns width and alignment, it is interesting to note the following conclusions which were arrived at by the sectional conferences which were held under the auspices of the Local Government Board in London during the year 1914 on the question of

Secretary of the Road Board, issued a "memorandum as to amendments with a view to a constructive road policy," one of which was as follows :—

"It should be provided in the Bill that the Minister shall have power on the advice of the Road Department or Board to prescribe the minimum width for arterial roads, i.e. to issue regulations providing that for the roads specified in the regulations, no new buildings shall be erected within so many yards of the centre of the highway without prejudice to the powers of local authorities to prescribe a greater width for that portion of the road passing through their areas. Similar powers should be conferred on County Councils to conserve the width of Class 1 and Class 2 roads within their areas. At present new houses are often allowed to be built up to the edge of a narrow but important road, without sufficient space being provided even for a footpath. The inevitable result is that the passage is permanently narrowed, or the local authority is put to the expense of securing the land and demolishing the buildings erected. In respect to preserving the width of arterial roads at the present time we are far behind the practices of our ancestors in the first quarter of the nineteenth century, as the roads through the south of London bear witness."

"Arterial Roads in Greater London". These conclusions may be summarised as follows:—

(1) That the outside roads are quite a separate problem to that of the existing roads within the County of London.

(2) That traffic necessities ought not to dominate the approaches to a Capital city.

(3) That liberal space should be left at all intersections of roads to meet traffic requirements.

(4) That widening and altering existing roads might be avoided to a large extent by the adoption of good relief roads after careful inspection of the district.

(5) That the formation of "greens" at road junctions is desirable.

(6) That building lines should be kept well back to allow space for trees and shrubs, etc.

(7) That the widths of arterial roads should be settled on definite principles, and the following widths were suggested: main roads should be 80 ft. wide, secondary roads, 40 ft. wide, and residential roads, 25 ft. wide, with 40 ft. clear width of air space between the houses.

Gradient.—On the question of gradient, so far as it affects traffic, it must be remembered that for self-propelled vehicles gradient is not of so much importance as for horse-drawn traffic.

Tractive Force and Gradient.—A motor makes light of gradients, but objects to awkward and dangerous corners. As, however, we are still in the transition stage, and have to cater for horses as well as motors, a few words on the subject may be useful. Of course, the question of gradients is largely governed by locality, but it has been laid down authoritatively that, given that a horse can draw one ton on a level road, he can only draw the following weights on the following gradients:—

1	in	100	·90	of a ton
1	,,	50	·81	,,
1	,,	40	·72	,,
1	,,	30	·64	,,
1	,,	20	·40	,,
1	,,	10	·25	,,

A horse can keep up a trot on a gradient of 1 in 20 with a light load.

Various Allowable Gradients.—The steepest gradients allowed by the engineers of the Ponts et Chausées in France for any road is 1 in 20. In America the maximum gradient for "important" roads is also 1 in 20, but in some of the States a gradient of 1 in 11 is allowed for roads of secondary importance and for "earth" roads.

Materials and Gradients.—The question of the material with which the surface of any carriage way is covered enters largely into the question of gradient, for it is evident that an ordinary water-bound macadam road could have a much steeper gradient than that of a carriage way covered with asphalt or even tarred macadam, which may become dangerously slippery under certain climatic conditions.

On this point it is interesting to note that Mr. Walker Smith[1] gives the following summary of the replies he had received from various surveyors to his question, "What is the maximum gradient upon which tar macadam is laid, and with what result as to slipperiness?"

Thirty replies were to the effect that from 1 in 13, to level, were safe in dry weather and no frost.

Ten replied that from 1 in 15 to 1 in 80 were slippery in frosty and foggy weather.

One reply that it was unsafe at 1 in 12.

It will be seen from the above replies that there is a considerable divergence of opinion as to what is a safe gradient for such a surface.

Some years ago, before the introduction of self-propelled traffic, the Local Government Board laid down a sort of rule that the maximum gradients should be as follows:—

Soft wood paving	1 in 20
Hard wood ,,	1 ,, 40
Asphalt ,,	1 ,, 60

but these limits are not adhered to at the present time.

[1] *Vide* "Dustless Roads Tar Macadam; a Practical Treatise for Engineers, Surveyors, and Others," by J. Walker Smith. Charles Griffin & Co., Ltd., London [p. 11].

Recently Fixed American Gradients.—In the final report of the Special Committee on Materials for Road Construction, presented to the American Society of Civil Engineers in January, 1918, the Committee recommended the following maximum limits for gradients, viz. :—

Asphalt block, gradient of	1 in 12·5
Bituminous surfaces, gradient of . .	1 ,, 16·6
,, concrete, gradient of . .	1 ,, 12·5
,, macadam, gradient of . .	1 ,, 12·5
Brick [bituminous filler], gradient of . .	1 ,, 8·3
Broken stone, gradient of	1 ,, 8·3
Cement concrete, gradient of . . .	1 ,, 12·5
Gravel, gradient of	1 ,, 8·3
Sheet asphalt, gradient of	1 ,, 20·0
Stone blocks [cement filler], gradient of .	1 ,, 11·0
,, ,, [bituminous filler], gradient of	1 ,, 6·6
Wood blocks, gradient of	1 ,, 25·0

Some of the above seem to be much steeper than would be allowed in this country, but we may assume that they are given after due consideration and investigation. It is as well to note that by "sheet asphalt" is not meant what we know as compressed rock asphalt, but that which we call a bituminous carpet.

Road Board on Gradients.—The Road Board did not lay down any hard and fast rules, but, in addition to those already given, they recommended that in the case of an impervious surface of any kind the gradient should not be steeper than 1 in 18, and that granite setts may be laid at gradients not steeper than 1 in 15, anything steeper than these should be either water-bound macadam, or some of the softer Yorkshire or Lancashire gritstone setts.

So long as horse traffic has to be met, the question of gradient, in connection with the description of the surface of the carriage way, must be carefully considered, and every highway engineer must use his judgment in connection with the exigencies of each case.

Camber.—With regard to the barrel or "camber" of the surface of a carriage way, so far as it affects traffic, the tendency is unfortunately almost universally to give an excessive gradient or pitch. The only object of camber is to pass off the water as quickly as possible to the side channels or water tables, as water is even a greater enemy to most descriptions of road surfaces than traffic. In the old days of water-bound macadam carriage ways, with no surface sealing, there was an undoubted tendency to overdo the camber as the surface was pervious, but now that more modern methods have been adopted, and the surfaces of the carriage ways are constructed so as to be almost entirely waterproof, the necessity for excessive camber no longer exists.

Objections to Excessive Camber.—The practical objections to excessive camber may be summarised as follows:—

(1) It tends to cause the traffic to seek the centre of the carriage way, thus leads to "tracking".

(2) It prevents the slow traffic keeping to the side of the road, as it is more difficult for horse and driver than on a level surface.

(3) With an impervious surface, excessive camber may cause side-slip, both of a self-propelled vehicle or of a horse.

(4) A high load is often tilted at such an angle over the footway as to be even dangerous to lamp-posts, awnings, and the like.

Early Rules for Amount of Camber.—One of the earliest methods for determining camber was to make the centre of the carriage way level with the head of the footway on each side. This rule for a 36-ft. street, with kerbs, say 5 ins. in depth, and $\frac{1}{4}$ in. to the foot-fall in the footpath, gave a cross-fall from the centre of about 1 in 22, which is obviously excessive.

Mr. Codrington, in his well-known book on Macadamised Roads, said that the cross-fall should not exceed 1 in 30. Mr. W. H. Wheeler, in 1900, said that the best form of camber is that of an ellipse, a very small inclination in the middle, and a steeper fall at the sides towards the channels of about 1 in 24. The late Mr. Strachan, when Surveyor of Chelsea, gave for a macadam road a segment of a circle rising in the centre $\frac{3}{8}$ in. for every foot of the half-width of the carriage way, this is about 1 in 32.

Many other experts have given various opinions on this question of camber, varying from 1 in 24 to 1 in 40, but the following suggestions as to the proper camber to give to various carriage way surfaces may form a basis on which some experiments might be made:—

SUGGESTED CAMBER FOR DIFFERENT ROAD SURFACES.

Natural rock asphalt and the like	1 in 60
Wood pavement	1 ,, 50
Granite and other stone setts	1 ,, 50
Tar macadam	1 ,, 48
Water-bound macadam tar painted	1 ,, 40
Ordinary water-bound macadam	1 ,, 34

Reduction of Camber.—There can be no doubt that at present there are numerous well justified complaints of excessive camber on a large number of the roads throughout the United Kingdom, and that, where possible, they should be reduced on reconstruction. This is, however, sometimes a difficult and costly proceeding, as it involves either the removal of the crown of the carriage way, thus weakening it, or the raising of the kerbs and pavements at the sides. Where there are tramways in the centre of a carriage way the problem is even more difficult, and there are numerous cases where, owing to their presence, the haunches or shoulders of the carriage way have an even dangerous amount of cross-fall.

In the case of country roads the reconstruction with reasonable cross-falls should not be so difficult, and with a little judgment it can easily be accomplished. It is to be hoped that in process of time the present tendency to excessive camber may be a thing of the past.

Report on Roads, Locomotives, etc., and Effects on Roads.—This chapter on "Traffic" would be incomplete without a reference to the following important report:—

In 1915, a Departmental Committee of the Local Government Board was appointed "to consider the Law and Regulations relating to the construction and use of Road Locomotives and Heavy Motor Cars in Great Britain," and their report and recommendations were issued in 1918.[1] A mass of evidence was laid before the Committee, which is very interesting to read, as no less than sixty-six expert witnesses were examined.

In their report the Committee review the numerous Acts and Regulations which had been framed since so long ago as 1831 with regard to self-propelled vehicles, and the "tangle" of all this legislation and the numerous amendments and alterations is unravelled. In their "general observations upon the evidence" they say:—

(1) That heavy mechanically-propelled traffic has enormously developed, will still further develop, and must play an "increasing part in the commercial and industrial life of the nation".

(2) That said traffic is no longer local in its character.

(3) "That it is quite possible to construct and maintain roads capable of carrying the traffic efficiently at a cost which, if equitably adjusted, would not be unreasonable."

(4) That as the traffic grows and becomes less local in character, the roads must be treated less from a local standpoint and more in accordance with the extended character of this traffic, with respect both to the cost, control, and administration of the roads.

The Committee were further of opinion that damage was caused to roads, in varying degrees, "due to differences in the character of the roads carrying the traffic, or to differences in the construction and use of the mechanically-propelled vehicles, and to a certain extent to both".

With regard to this damage they say:—

That in the case of *paved roads* [setts, wood, asphalt] laid on concrete "the damage is largely due to iron and steel-tyred traffic" and not to rubber-tyred traffic, which "appears to have no serious effect upon sett-paved roads even when travelling at high speed". And that this is much the same with *wood paving* where the surface has been properly main-

[1] Published by H.M. Stationery Office and can be purchased through any bookseller. Part I., the Report, is 4d. net, and Part II., Minutes of Evidence, is 3s. 6d. net.

tained, and that, "given the same conditions, *natural or rock asphalt* on concrete is not seriously affected by either class of traffic, although one instance was given of damage caused to this class of pavement by the steel-tyred heavy motor traffic".

"That as regards the more modern forms of road construction in which *tar*, *pitch*, or *bitumen* is used as a binder, or matrix, the evidence is conflicting, but there would appear to be no doubt that roads of this class, if properly constructed and maintained, will carry a considerable volume of heavy traffic without undue damage."

"That in the case of *water-bound macadam roads* the damage is mainly due to rubber-tyred traffic."

The above pronouncements are exceedingly valuable as they were arrived at after a careful consideration of a great deal of evidence laid before the Committee.

They then give the principal causes of damage to roads, which are as follows:—

In the case of traction engine traffic it is attributed to—

(*a*) the weight of the engine, and of the loaded waggons which it draws;

(*b*) the haulage of exceptionally heavy pieces of machinery or similar loads on trucks having iron-tyred wheels of small diameter;

(*c*) the use of driving wheels fitted with diagonal crossbars and of steering wheels fitted with narrow bands;

(*d*) the slipping of the driving wheels in the efforts of the engine to haul a heavy load;

(*e*) the use of waggons generally with wheels of small diameter.

In the case of heavy motor traffic it is attributed to—

(*a*) the laden weight of the motor vehicle and the uneven distribution of the weight over the axles;

(*b*) the use of wheels of small diameter;

(*c*) the propulsive effort of the vehicle;

(*d*) the fact that, owing to the camber of the road and inequalities in the surface of the road, the full width of *steel tyres* does not come into contact with the road surface; the weight is thus concentrated upon the part of the tyre actually in contact with the road surface, and the sharp edge of the tyre cuts into the road;

(*e*) the action of the *solid rubber tyre* as it expands and contracts when coming into contact with, and leaving, the road surface; it is contended that in the case of water-bound roads, for example, this action of the tyre has a disturbing effect upon the road surface, that the materials of which the road surface is formed are loosened and forced out, and that in the case of the twin rubber tyre the materials are "pinched" or "squeezed" between the two tyres as they expand;

(*f*) the hardness of the solid rubber tyre when worn;

(*g*) the impact and the speed, more especially when there are inequalities in the surface, or pot-holes due to lack of repair;

(*h*) the disregard of the regulations limiting weight and speed, and the failure to enforce them.

In addition, special damage is attributed to motor omnibus services, by reason of (1) the regularity of the service, viz. the constant passage over a road of vehicles of identical construction and the frequent starting and stopping of the omnibuses, often at fixed points along the road; and (2) the "character" of the load and the springing of the wheels.

The Committee then dealt at considerable length with the question of the "weight of locomotives". They point out that existing provisions do not contain any definition of the expression "weight of the locomotive". Road authorities naturally want to know the *maximum* weight to be borne by the roads when the locomotive is loaded to its full capacity with water, fuel, loose tools, etc., in other words, a "ready for the road" weight.

Their final recommendation on this point is that "the maximum limit of weight of 14 tons should remain unaltered as regards ordinary road locomotives, and should be raised to 18 tons in the case of the Boulton wheel traction engines. The expression 'weight' should be more clearly defined."

The reason why more weight is allowed for Boulton block driving wheels, is that it was conclusively proved by witnesses and by practical trials that an engine fitted with these wheels does less damage to a road than ordinary cross-barred driving wheels.

As to the means to be adopted for ascertaining the real weight of a locomotive when on the road, they recommend that "the licensing authority should be required to ascertain the correct weight of a locomotive by causing the locomotive to be weighed before it is licensed or registered".

The Committee considered a great deal of evidence that was laid before them as to the "construction of wheels of locomotives," i.e. as to their diameter, width of tyres, and axle weight, and they considered "how far the statutory provisions can be satisfactory which—

"(*a*) require a width of wheel proportionate to the weight of the locomotive irrespective of the weight on the axle to which the wheel is attached;

"(*b*) leave unregarded the steering wheels of a traction engine;

"(*c*) make no distinction in the matter of the width or diameter of the driving wheels of a traction engine between a smooth-soled wheel and a wheel shod with diagonal cross-bars."

They recommended that—

(1) The distinction made by Sec. 28 of the Act of 1878 between "a locomotive not drawing any carriage" and "a locomotive drawing any waggon or carriage" should be abolished as obsolete.

(2) That the tyre of each wheel, whether steering wheel or driving wheel, should be at least 5 ins. in width, and that, subject to that minimum, the tyres of the driving wheels should be of the width required by sub-section (2) of the above section.

They discussed the question of narrow bands on steering wheels, and came to the conclusion they were necessary, but should not be less than 5 ins. in width. With regard to cross-bars on driving wheels—a very important point, as there can be no doubt that these cross-bars cut up some roads to a considerable extent and do great damage—the Committee could not see their way to an absolute prohibition of this device, as the witnesses representing the traction engine industry were most emphatic on the point, that traction engines could not get a "grip" on the road surface without them, and that on steep gradients smooth wheels would be dangerous, one witness asserting that "the engines might as well be scrapped if we had to use smooth wheels".

The Committee considered some alternative suggestions, and finally decided that any additional requirement should be recorded as follows:—

"The cross-bars shall be disposed throughout the tyre so that nowhere shall the aggregate extent of the cross-bar, or cross-bars, in the course of a straight line drawn horizontally across the circumference of the wheel be less than one-half of the width of the tyre."

They also considered that the use of cross-bars should not be permitted on wheels of less than 4 ft. 6 ins. in diameter.

In view of the difficulties besetting this question we must accept this decision of the Committee as the best compromise that could be effected, and road makers will have to put up with the damage which is certain to be caused even with the scientific restrictions imposed under the recommendation.

The Committee also dealt with the rather complicated question of the weights to be allowed for waggons or trailers drawn by locomotives, and the "antiquated and unsatisfactory" regulations and provisions at present existing, which date back to the General Turnpike Act of 1822! After exhaustively dealing with the subject, they made the following recommendations which are set out in full:—

"We recommend that the new provisions should give effect to the following proposals:—

"(*a*) The weight of the waggon unladen should be marked on the waggon, and also the axle weight of each axle of the waggon, if the unladen weight of the waggon exceeds 1 ton.

"(*b*) No maximum limit should be placed on the weight of the waggon unladen.

"(*c*) The tyre of each wheel of a waggon which exceeds 1 ton in weight unladen should be smooth, and, where it touches the ground, flat, except that each edge of the tyre should be rounded to the extent of not more than $\frac{1}{4}$ in. where the tyre is less than 5 ins. in width, and to the extent of not more than $\frac{1}{2}$ in. where the tyre is 5 ins. or more than 5 ins. in width.

"(*d*) The tyre should be not less than 3 ins. wide, and, subject thereto, the width of the tyre of each wheel should be determined in the same manner as the width of the iron or steel tyre on the wheel of a heavy motor trailer, namely, by reference to the number of units of axle weight of the axle to which the wheel is attached, the units of axle weight for varying diameters to be those prescribed for wheels of heavy motor traïlers.

"(*e*) The diameter of each wheel of a waggon exceeding 1 ton in weight unladen should, if the waggon is constructed with suitable and sufficient springs between each axle and the frame of the waggon, be not less than 2 ft. 6 ins., and, if the waggon is not so constructed, be not less than 3 ft. For axle weights exceeding 4 tons, the following scale of minimum diameters should be prescribed :—

	Waggons with Springs. Ft. Ins.	Waggons without Springs. Ft. Ins.
Axle weight exceeding 4 tons, but not 5 tons	3 0	3 6
,, ,, ,, 5 ,, ,, 6 ,,	3 6	4 0
,, ,, ,, 6 ,, ,, 7 ,,	4 0	—

"(*f*) The axle weight of an axle should not exceed the axle weight of that axle marked on the waggon, and the axle weight marked on the waggon should not exceed 7 tons if the waggon is constructed with springs, or 6 tons if the waggon is not so constructed.

"The above rules should not apply to a threshing waggon, plough, or other agricultural implement.

"We do not suggest any alteration in the existing provisions which (*a*) limit the number of loaded waggons drawn by a locomotive, or (*b*) authorise the highway authorities to allow upon roads in their own areas the carrying of loads in excess of the weights ordinarily permitted."

With reference to occasional very heavy loads exceeding 16 tons, such as boilers, machinery, etc., which are occasionally drawn by locomotives on the roads, causing immense damage even to a hard granite sett pavement, they draw attention to the waggons used for this purpose at Dundee, where "waggons having wheels tyred with wood instead of iron have been used with marked success". They also dealt with the question of the necessity to give a reasonable notice to the road authority when such heavy loads were intended to be drawn, and they came to the conclusion that the case would be met if such notice was given at least seventy-two hours to the County Surveyor and forty-eight hours to the County Borough Surveyor before the journey was commenced.

The Committee then dealt at even greater length with the subject of Heavy Motor Cars; weight, construction, and speed. They point out that the question is more complicated, and presents more difficulties than the question of road locomotives, as they involve so many types, from "the Foden tipping waggon to the latest type of motor omnibus".

They had to consider questions of weight, speed, diameter of wheel, width and material of tyre, definition of weight, maximum "laden" weights and axle weights, construction of wheels, rubber tyres, length of vehicle, wheel base, overhang behind driving axle, the London motor bus, restriction of heavy traffic on unsuitable roads, roads on break up of frost, smoke and visible vapour, obstruction of fast traffic, bridges of insufficient strength, extraordinary traffic, and many other questions.

It would take up too much space to give in detail the valuable suggestions that were made, but the following final recommendations with reference to this portion of their submission are given in full:—

"(1) The maximum unladen weight of a heavy motor car should be increased to 6 tons, and the combined unladen weight of the car and trailer should be increased to 8 tons.

"(2) The definition of the unladen weight of a motor car should be amended.

"(3) The maximum laden weight and the maximum axle weight should not be altered.

"(4) Before a heavy motor car is registered, it should be weighed by, or in the presence of, an officer of the registering authority and its correct unladen weight definitely ascertained, and the registering authority should be required to satisfy themselves that the correct weights and speed are marked on the car. The registering authority should be authorised to require a motor car to be weighed, upon an application for registration, if the declared weight of the car unladen does not exceed 2 tons.

"(5) The distance which a heavy motor car may be required to be driven to a weighing machine for the purpose of testing the axle weight should be increased to one mile, and registering and road authorities should for this purpose be empowered to require a car to be driven to a weighing machine from any distance beyond the one mile limit, subject to provisions as to the payment of compensation and the delivery of a certificate of weight. Heavier penalties should be imposed in the case of habitual offenders against the regulations limiting axle weight.

"(6) The minimum diameter for wheels of heavy motors fitted with iron, steel, or other hard tyres should be raised from 2 ft. to 2 ft. 9 ins., and a scale of minimum diameters should be prescribed, according to registered axle weight, where the registered axle weight exceeds 4 tons.

"(7) The edges of a tyre of iron, steel, or other hard material should be rounded. Bevelled edges should not be permitted. In other respects the regulations relating to the use of this description of tyre should not be altered.

"(8) The diameter of any wheel of a heavy motor, which is fitted with a solid rubber tyre or other tyre of a soft or elastic material, not being a pneumatic tyre, should not be less than 2 ft. 6 ins. No regulation need be made as to the size or shape of the tyre itself.

"(9) The maximum overall length of a heavy motor car should not exceed 26 ft. The overhang behind the driving axle should not exceed seven twenty-fourths of the overall length of the car. These requirements should apply to motor omnibuses.

"(10) Heavy motor cars registered and in use before amending regulations come into operation should be exempted from compliance with any new requirements as to construction, and the loads which such cars are at present permitted to carry should not be reduced.

"(11) The existing law, which permits a motor car to be used to draw one trailer only, should be retained. Certain minor amendments should be made in the regulations relating to the use of trailers.

"(12) The present speed limit regulations should be retained, subject to the following amendments, namely, (*a*) that the speed for a heavy motor car tyred with iron, steel, or other hard substance should not in any case exceed five miles an hour, and (*b*) that where a heavy motor car draws a trailer and the wheels of both vehicles are fitted with rubber tyres, the maximum speed should be eight miles an hour.

"(13) Heavier penalties should be imposed for a second or subsequent offence against the speed limit regulations.

"*Restriction of Heavy Traffic on Unsuitable Roads.*

"(14) Motor omnibus and similar passenger traffic should be brought under special regulations, and the procedure should be that laid down in Section 20 of the Local Government (Emergency Provisions) Act, 1916.

"(15) Powers should be conferred on the Local Government Board and the road authorities to regulate through heavy motor traffic in order to secure that such traffic is, as far as practicable, required to use the roads which are constructed to carry it.

"(16) County Councils should be given power to regulate traffic upon a road which is under repair or reconstruction, and to divert the traffic on to another road."

The above report touches so largely on some of the present traffic problems that they have been referred to somewhat *in extenso*.

Varying Speeds Congest Traffic.—In concluding this chapter on "Traffic," it may be of interest to see the following table, which was carefully prepared to show what description of vehicles caused the most obstruction to traffic in the streets of the metropolis, and although it has nothing to do with the effect of traffic on the surface of the carriage way, it may be useful for reference.

If the coefficient of obstruction or "traffic unit" attributable to a motor cab or carriage be taken at one, the following numbers may be assigned to each class of vehicle:—

Trade Vehicles.		Passenger Vehicles.	
One horse (fast)	3	Electric trams	10
,, ,, (slow)	7	Omnibuses (horse)	5
Two horse (fast)	4	,, (motor)	3
,, ,, (slow)	10	Cabs (horse)	2
Motor (fast)	2	,, (motor)	1
,, (slow)	5	Carriages (horse)	2
		,, (motor)	1
Barrows	6		
Cycles	½		

From this it appears that the slow two-horse van and the tramcar are the worst offenders in delaying traffic, and those of us who "know our London" can readily confirm the above "table".

To show the mobility of the motor cab, no taxi cab is registered at Scotland Yard by the police which cannot turn in a circle of 25 ft. diameter or less.

Suggested Improvement of Traffic.—With regard to the general improvement of the highly congested traffic in many of the streets in the metropolis, various suggestions have from time to time been made, of which the following are worthy of consideration:—

(1) Slow traffic to be prohibited in certain selected streets during certain hours of the day.

(2) In very narrow streets the traffic to be confined to one direction only where this is possible.

(3) Vehicles allowed to stand at the sides of streets for loading and unloading purposes should have a time limit, and the practice should be discouraged as much as possible.

(4) The turning of empty taxi cabs in busy streets should be discouraged.

(5) All vehicles should keep within a limited distance of the kerb on their near side. This rule is at present neglected,

and seriously diminishes the available space for the other traffic.

The congestion of traffic in the London streets is becoming more and more serious, and no doubt steps will have to be taken before long to improve the present state of affairs.

This concludes the chapter on "Traffic". The next subject to be dealt with is that of Water-bound Macadam Roads.

CHAPTER III.

WATER-BOUND MACADAMISED ROADS.

IT is evident that for some time to come it will still be necessary to construct what are known as Water-bound Macadamised Roads, whether left with untreated surfaces, or covered afterwards with a thin skin of some bituminous mixture. Although it is sometimes contended that this description of road construction is a thing of the past, and that it is better, and even more economical, to construct bituminous-bound roads and to abandon altogether the construction of water-bound macadam roads, be this as it may, where the traffic is light they are still likely to be constructed and if well made should have a fairly long life with moderate repairs. The outcry raised against this description of road was primarily caused by the fact that a very large number of roads in this country had been badly made in the first instance and could only have been put right at very great expense.

Description of Early Roads.—As an instance of how badly constructed were the roads of the past, it is interesting to note that in 1737, a Mr. Robert Philips, when writing on the construction of roads, said: "Roads may be considered as made up of three sorts of matter, first, stones as big as eggs and less; second, a yielding substance such as mould; and third, water". Again in "The Road Maker's Guide," written in 1805 by a Mr. R. R. Bradley, he said: "The first principle apparently impressed by the Almighty Power upon all inert matter is a tendency to become proper for the system of vegetation . . . from this cause it becomes the proper system of the road maker to select such materials for that use as are most distant from the capacity of supporting vegetables". Small wonder then that another writer only forty years ago said: "Day by day they try, with incalculable efforts, to perfect macadam. They have perfected their watering in summer and sweeping in winter, they have substituted, at great cost, granite in place of limestone, they have multiplied their road labourers; each morning the devastations of the day before are repaired, but when the stream of traffic again covers the street, the dirt recovers its rights, and during 300 days of the year the roadway becomes an ocean of mud or a desert of infected dust."

It is unnecessary to give details of how a water-bound macadamised road should be constructed. If Thomas Telford's specification is strictly followed the road should be satisfactory.

Failure of Water-bound Roads.—Many of the failures of this class of road are due to the following defects:—

(1) Unstable natural foundation.
(2) Want of drainage.
(3) No properly constructed bottom course.
(4) Soft, or inappropriate, metal.
(5) Improper binding.
(6) Too little camber.
(7) Want of strength in the haunches.

Need of Foundation.—It is evident that if the natural foundation is unstable the structure of the road sinks into it, and this can often be detected when opening an old road where a depth of 2 ft. of metalling is found, or even more, and yet the road is unsatisfactory.

The Evil of Water.—Water is the great enemy of all roads, and especially of water-bound roads, a properly constructed bottom course of large stones not only supports the superstructure but also gets rid of the water falling on the surface of such a road. Drainage is therefore essential and another necessity for this foundation is that it prevents the "spewing" up of the natural soil into the metal foundation.

The Metal.—With regard to the metal; formerly any local stone was considered good enough for road construction, provided it was cheap. This was of course a very short-sighted policy. A cheap bad metal is dear at any price. Further reference will be made to the question of road stone later.

Binding.—As to the binding, here again anything "handy," and local, was considered sufficient, with the result that road scrapings, or sweepings, and even earth and mud were considered good enough for binding the metal.

Camber.—Many roads were made of insufficient, or badly designed, camber, and consequently the object for which camber is necessary was defeated and water stood on the road instead of immediately flowing off to the sides.

Lateral Spreading.—One of the greatest causes of failure in the older water-bound roads was "spreading" due to the weakness of the haunches. It is evident that unless a carriage way is properly supported at the sides, the surface is compressed by the traffic and spreads laterally towards each side. There are many cases where the metal of a road has spread in this manner and been squeezed under the grass verges for distances of two or more feet.

Inter-attrition.—The great object to be aimed at in the construction of a macadam road is to make it a monolithic body of such strength that the separate stones of which it is constructed shall move as little as possible under the weights and rolling of the traffic.

Such movements tend to grind the stones one against the other even at some depth from the surface, and what is known as inter-attrition is set up. It is remarkable in our old macadamised roads to find, even at considerable depth, that the angular stones of which the road had been originally constructed have assumed a rounded shape due to this cause. The elimination of this frictional movement amongst the stones is the principal claim of more modern road construction, as it is claimed that if all the voids or crevices between the stones can be filled with a proper and lasting "filler" or binding material, this action of inter-attrition would cease.

It is impossible to prevent this movement with ordinary water-bound macadam roads, as although certain stones when pulverised become more or less "cementitious," the quality of this "cementition" is not resilient, nor can the effect be lasting.

The Best Stone.—The question of the best description of stone to be used for the construction of macadamised roads, and the size to which it should be broken, has lately been much discussed, and has received much more scientific attention than pertained in former years. With regard to the most suitable rocks to be employed for road metal, the qualities necessary may be summed up as follows:—

(1) Power to resist compression.
(2) " " abrasion.
(3) " " the action of weather.
(4) " assist cementation.

Road Materials.—In the first edition of the author's book, "The Municipal and Sanitary Engineer's Handbook," published in 1883, he gave the following list of rocks which he considered suitable for road metal:—

(1) *Syenite.*—This is a granite in which hornblende takes the place of mica, and is an excellent road material; the darker the colour the more durable it is found to be.

(2) *Granite.*—This should have more felspar than quartz, and have as little mica as possible; the closer the grain the better. Coarse-grained granites soon decompose.[1]

(3) *Trappean Rocks.*—Some of these are excellent for road metal. Basalts of dark colour and close grain should be selected. Greenstones with similar characteristics are good, as is also whinstone.

(4) *Gneiss.*—Is inferior to granite; it has mica in layers and is not a good road metal.

(5) *Clay Slates.*—These are useless, as they crumble on exposure, or degenerate into mud.

[1] All granites are not suitable for road making. When a granite becomes weathered the felspar may decompose into kaolin or china clay. The commencement of this alteration is indicated under the microscope by the turbidity of the felspar. At the quarries it is often necessary to reject large quantities of stone for road purposes because of this change. All the toughness is gone out of it, and the quarrymen speak of it as "dead".

(6) *Limestone.*—The metamorphic, silurian, and carboniferous limestones may be used if crystalline in appearance, but the Lias and Oolitic are of little use.

(7) *Sandstone.*—Some of these, if cherty, or containing a large percentage of iron, may be used, but, as a rule, they are quite unfitted for use as a road metal.

(8) *Flints.*—These, if tough, make excellent roadways; but, unfortunately, they are sometimes too brittle for heavy traffic. Surface-picked flints are better than those from a quarry.[1]

(9) *Pebbles.*—These are found on sea-shores and in rivers. They are composed of very various rocks, and are much water-worn and rounded; when broken they sometimes answer very well if mixed with gravel to bind them.

(10) *Gravel.*—This, if of a flinty character, and not too much mixed with earthy matter, makes good roads for light traffic, if carefully watched, or well rolled during formation. Pit gravel should always be screened through wire screens of $1\frac{1}{2}$ and $1\frac{3}{4}$ gauge, and the small can be used for footpaths.

Although the above was written nearly forty years ago, the author is of opinion that it is still a very reliable list of rocks suitable for road making purposes, and that time, as well as modern scientific research, have endorsed the value of the above list of stones.

For instance, a recent statement as to the geological formations suitable for road-making stones may be shortly given as follows:—

(1) *Trap Rocks.*—These are excellent as a rule.

(2) *Rhyolite* or other igneous rocks are hard, but not so tough as trap rocks. They lack the interlocking structure.

(3) *Gabbro.*—Not quite so good as Nos. 1 and 2.

(4) *Granites.*—These vary considerably, but many of them are excellent; they are granular without being interlocking.

(5) *Slates and Schists.*—These, as a rule, are not of much value, they split into flakes and manufacture mud and dust.

[1] A flinty or quartzose stone seems to harden with exposure. This is notably the case with pebbles; old pebble paving taken up and broken makes a most hard and durable road metal, but does not bind readily.

(6) *Quartzite.*—This is brittle, but makes good roads for certain classes of light traffic.

(7) *Limestones.*—These are very varied, some make good roads, but they are apt to make a slippery road and much dust.

(8) *Sandstones.*—These are, as a rule, failures.

(9) *Gravel.*—The glacial and beach gravels are largely used, and make good roads for light traffic. They are widely distributed, easily quarried, and require no breaking.

On comparing the two lists the author is of opinion that his list is the better and more practical one of the two.

The following conclusions were arrived at in a report by Edwin C. E. Lord of the Office of Public Roads, Washington, U.S.A., in 1907:—

(1) Igneous and metamorphic rocks, owing to a higher degree of crystallisation and a preponderance of silicate minerals, offer a greater resistance to abrasion than nearly all varieties of sedimentary rocks.

(2) The coarse-grained intrusive rocks of the igneous class are harder, but break more readily under impact than the finer-grained volcanic varieties of like mineral composition.

(3) The deleterious effect of atmospheric weathering on the wearing qualities of rocks has been demonstrated.

(4) The cementing value of rocks is, to a certain degree, measured by the abundance of secondary minerals resulting from rock decay.

(5) Metamorphic rocks have, as a rule, a low binding power, owing to a regeneration of secondary minerals and to the effects of heat and pressure. The foliated types part readily along planes of schistosity, and, therefore, are not well adapted to road construction.

(6) The quantitative mineral analysis of rocks serves, to a certain extent, as a measure of their useful properties for road construction.

The above is useful as showing the opinion of an American road expert in 1907; and the following table, emanating from the same source, is a fair geological guide of the three classes of rocks mentioned therein:—

GENERAL CLASSIFICATION OF ROCKS.

Class.	Type.	Family.
I. Igneous	1. Intrusive (plutonic)	a. Granite b. Syenite c. Diorite d. Gabbro e. Peridotite
	2. Extrusive (volcanic)	a. Rhyolite b. Trachyte c. Andesite d. Basalt and diabase
II. Sedimentary	1. Calcareous	a. Limestone b. Dolomite
	2. Siliceous	a. Shale b. Sandstone c. Chert (flint)
III. Metamorphic	1. Foliated	a. Gneiss b. Schist c. Amphibolite
	2. Nonfoliated	a. Slate b. Quartzite c. Eclogite d. Marble

Artificial Tests of Metal.—Formerly there were but few artificial tests made with stones to ascertain whether they were suitable as road material or not. The usual test was to lay a certain length of the stone on a carriage way and then watch its behaviour. Now it is possible to carry out laboratory tests, which act as a guide in the selection of suitable stones, and these, added to the actual behaviour of the stone when laid, are bound to give reliable data. The artificial tests are also valuable as a guide in the selection of stones from various available quarries, and also to prevent the opening up of a quarry which could only produce useless stone for road purposes. There are several tests, and a number of special ways of applying them, but the following list and description may be useful:—

(1) *Specific Gravity.*—This test has so far not been of much value in determining the quality of a stone which would be of use as road metal. For instance, clay slate has a higher specific gravity than flint, and yet the former is useless as a road metal, whereas the latter is often employed for the purpose. Taken, however, in conjunction with other qualities

this test is sometimes a determining factor. It is also of considerable value in determining the weight of a cubic yard of broken stone, or how far a ton of broken stone of a known specific gravity will go. The specific gravity is ascertained in various ways, but, shortly, it is the weight of the displaced water divided into the weight of the stone; for instance, if the weight of the stone in air is 10 lbs. and the weight of the displaced water is 6 lbs., the specific gravity is 1·666. If the specific gravity is multiplied by 62·4 this will give the weight of a cubic foot of the particular stone.

(2) *Absorption.*—This test is important as an absorbent stone will not make a good road metal, it is liable to disintegrate, and also to split by the action of frost. One method of carrying out this test is as follows:—

(*a*) Weigh the sample piece of stone when dry; (*b*) then immerse it in water and immediately weigh it when thus submerged; (*c*) leave it submerged for ninety-six hours and then weigh it whilst still submerged; (*w*) the number of lbs. of water absorbed will be arrived at by the following simple sum:—

$$w = \frac{c - b}{a - b} \times 62{\cdot}4.$$

(3) *Abrasion.*—This test is one of the most important, as abrasion, or attrition, is one of the chief factors in the failure of a road stone. For many years past the French road engineers have adopted tests for abrasion, and the author gave a description of this method in the 3rd edition of his book, "The Municipal and Sanitary Engineer's Handbook," published in 1898, but he believes that Mr. E. J. Lovegrove, Borough Surveyor of Hornsey, was the first engineer in this country to devise and use a machine for this purpose, on scientific lines, which he designated a "Rattler".[1] The modern French method is to obtain a percentage of wear in the following manner:—

About ten pounds weight of stone broken to sizes varying

[1] *See* "Road Making Stones: Attrition Tests in the light of Petrology," by Lovegrove, Flett, and Howe. Published by the St. Bride's Press, Ltd., London.

between $1\frac{1}{2}$ ins. to 3 ins. gauge, are carefully weighed in bulk and are placed in a cast-iron cylinder rotating, diagonally, at a speed of 2,000 revolutions per hour. This is kept up for five hours, and the contents carefully emptied on to a table. All the abraded portions of the stone under one-sixteenth of an inch are carefully weighed and the percentage of this wear is deducted from the original weight of the stone and thus becomes the standard percentage of attrition. The average of, at least, three tests is taken as the coefficient of resistance to wear for that particular stone, and observations are also recorded on the character of the mud produced by mixing the abraded portions with water, as some stones when used for road metal give a more slippery mud than others, probably due to the absence of silica.

(4) *Hardness.*—At the Teddington National Physical Laboratory two specimens of the stone to be tested are carefully weighed and then pressed, with a regulated uniform pressure of 250 grammes per square centimetre of area, against the surface of a cast-steel disc or plate, rotating horizontally at a given speed. After 1,000 revolutions of the disc the specimens are again carefully weighed and the loss by weight is the inverse ratio of the hardness.

(5) *Toughness.*—This is measured by the power of the stone to resist fracture under a given number of measured blows. This is achieved by what is known as an "impact" machine, which is somewhat on the lines of a very small pile driver. A small cylinder of the rock [cut one inch in diameter and one inch in length] is placed in the machine and is then subjected to repeated blows of a small "monkey," weighing about four pounds, from a small height. This height is increased between each blow about a third of an inch until fracture takes place. Toughness, though very desirable in a road stone, is not everything, as leather is very tough, but would not make a good road metal.

(6) *Cementitious Value.*—This is somewhat of a modern test and is only of value to determine stones suitable for water-bound roads. The test for this value is as follows:—

A portion of the stone is pulverised so as to pass through a 0·25 millimetre sieve; this is then mixed with water with a stiff dough, then allowed to "season" for twenty-four hours, when it is then moulded into small cylinders about 25 millimetres in diameter and 25 millimetres in height. These are dried in air for twelve hours and subsequently in a steam bath for another twelve hours. They are then placed in an "impact" machine, which allows a hammer of light weight to fall a very small distance upon the end of the cylinder. The number of blows required to crush the sample is the cementitious value. It is stated that when the number of blows required to fracture the cylinder lies between 100 and 500 the cementitious value is rated as excellent; between 75 and 100 as very good; between 25 and 75 as good; and below 25 as fair or poor. Many stones of the limestone series are cementitious, but such stones are unsuitable for roads of heavy traffic, so that the cementitious value of a road stone can only be taken in conjunction with other qualities.

(7) *Microscopic Examination.*—This examination is useful as the qualities of rocks suitable for road construction are found, in some degree, to depend on the arrangement, character, and size of their original and secondary mineral constituents, and also of the size and shape of the cavities between these constituents. Nothing very definite has yet been arrived at with regard to these microscopic studies, and further investigation and research appear to be necessary. The geological and petrological formation of a rock does not always indicate any special value as a road stone. It is found that stone from the same quarry, and apparently of the same texture, does not always mean that the metal will have the same wearing qualities in actual practice; hence something more is required, and hitherto the only way to test these wearing qualities was by metalling a certain length of road with the particular stone and to note the effect of the traffic upon it.

Mechanical Tests of Road Surfaces.—At the Second Irish Road Congress, which was held in the year 1911, Mr. Robert J. Kirwan, the County Surveyor of Sligo, drew attention to a road-metal testing machine which he had designed, whereby, he contended, an actual test might be made of any given construction of road surface by means of a wheel rolling on the surface for a given time.

This machine was never constructed, but the design appears to be of some merit as the following sketch elevation will show :—

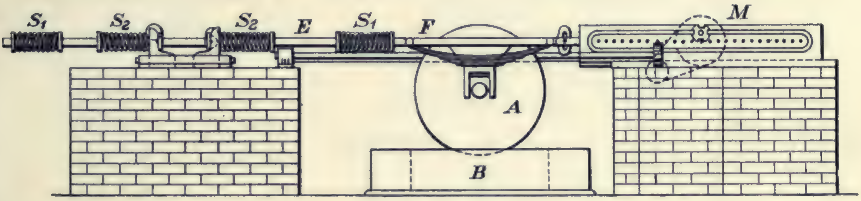


FIG. 3.

The material to be tested is built up in a cast-iron trough, B, and the test wheel, A, is moved over the surface longitudinally and transversely. This wheel revolves on a sleeve so that the whole surface of the material is tested. The wheel is actuated by means of a "mangle" motion, M, driven by suitable power applied to the pulley. The shafts driving the wheels are provided with springs, S, in order to absorb the momentum of the moving parts and accelerate their motion on the return stroke.

Physical Laboratory Tests.—In the year 1912, however, at the suggestion of Colonel R. E. Crompton, C.B., Consulting Engineer to the Road Board, a road-testing machine, on a large scale, was designed and erected at the National Physical Laboratory, Teddington.

By the courtesy of Mr. R. G. Batson, who had charge of the road stone tests at this Laboratory, the author is permitted to give the following particulars and description of this machine which was prepared for him by Mr. Batson :—

The machine consists of a circular track 30 ins. wide having a mean diameter of 34 ft. The endurance of the central 24 ins. of this track is tested by the rolling on it of eight steel-tyred wheels, 3 ins. wide and 39 ins. diameter. The wheels are at an angular distance of 45 degrees from each other and are coned so as to give pure rolling without any slip. Each wheel is rotated by a separate 2 H.P. electric motor mounted on a steel arm which revolves round a centre post, and the current for the eight motors is carried through slip rings attached to the centre post. The radial distribution of the wheels is such that the whole width of 24 ins. is covered in one revolution of the arms, and in order to prevent, as far as possible, the formation of ruts in the tested surface, each wheel is moved backwards and forwards radially by a cam mechanism through a distance of 1 in.

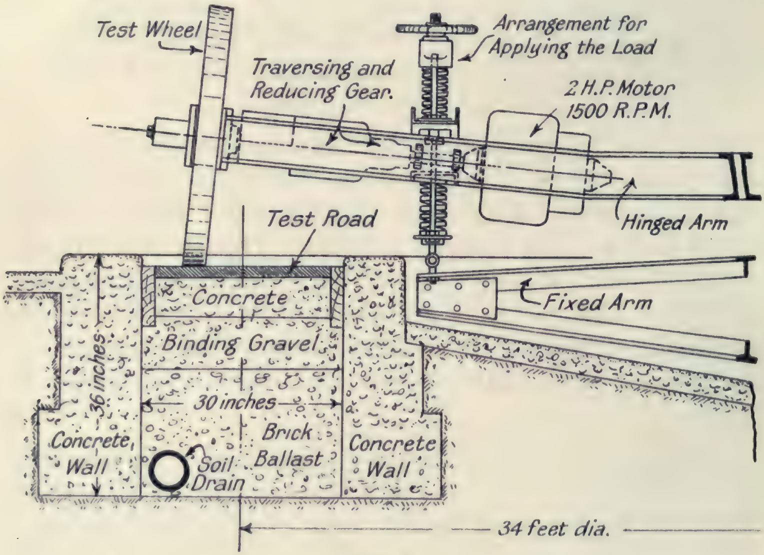
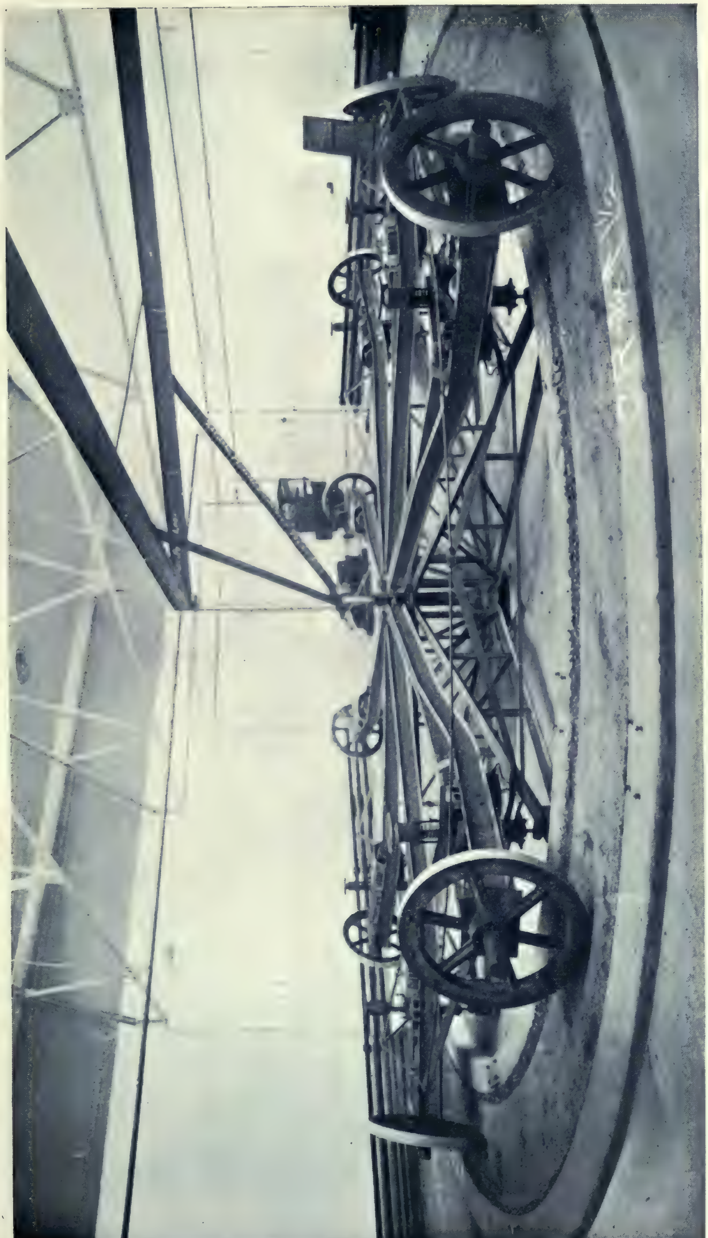
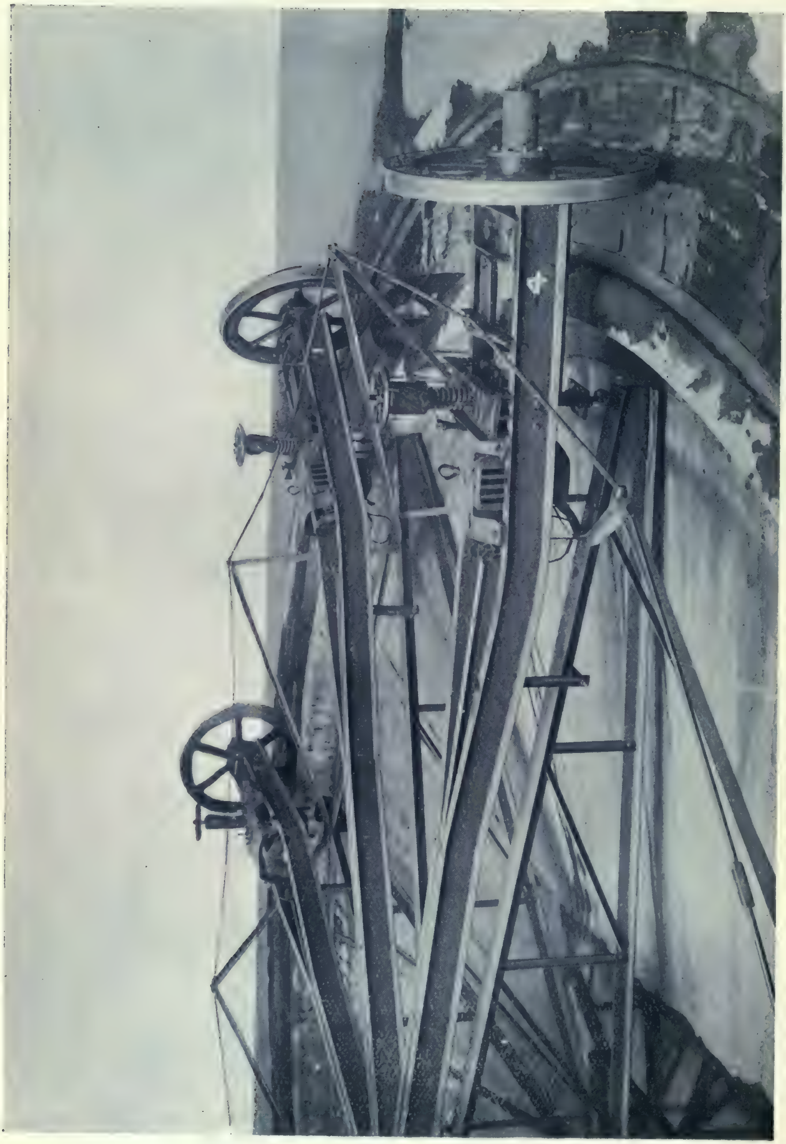


Fig. 4.

The eight arms are all hinged to a rotating boss on the centre post, and, at their outer ends, are connected by spiral springs to eight corresponding cantilevers rigidly fixed to a second rotating boss connected with the former and immediately below it. The pressure of each wheel on the track can be adjusted to any desired value up to one ton. Photographs of the machine are given in Plates I. and II., and a section of the test road and of one wheel in Fig. 4.



Teddington Road Testing Machine



Teddington Road Testing Machine.

In order to investigate the method of the formation of waves and the amount of deformation of the surface of the model tracks, an apparatus is used for drawing the shape of the road surface at a number of different paths. This apparatus, shown in Plates III. and IV., consists of an iron frame or carriage on three wheels, which, when in use, is attached to one of the arms of the testing machine and runs on the concrete walls bounding the road surface under test. In the middle of this frame, at right angles to the track, is a moving carriage carrying a drawing board on

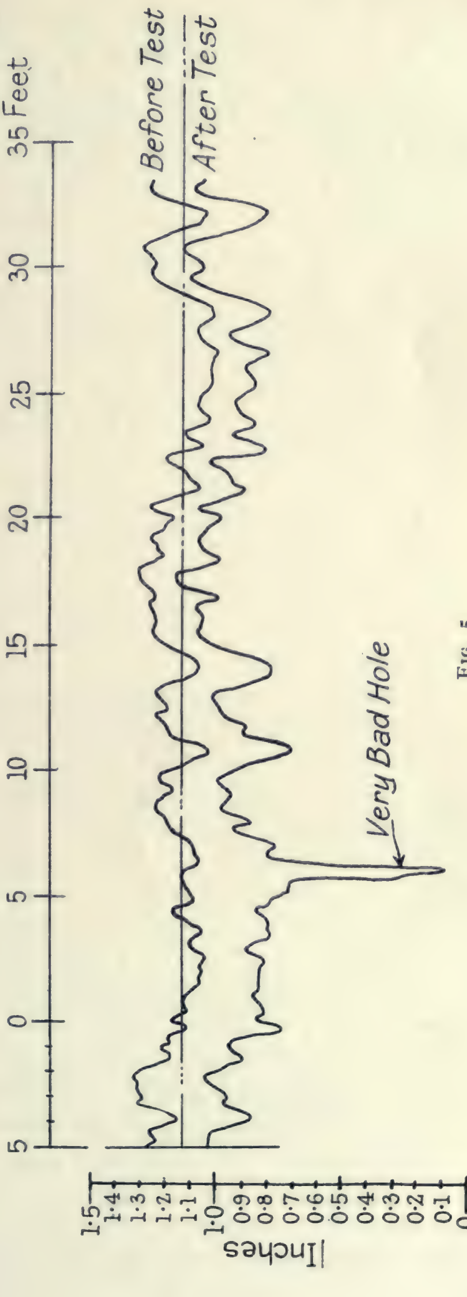
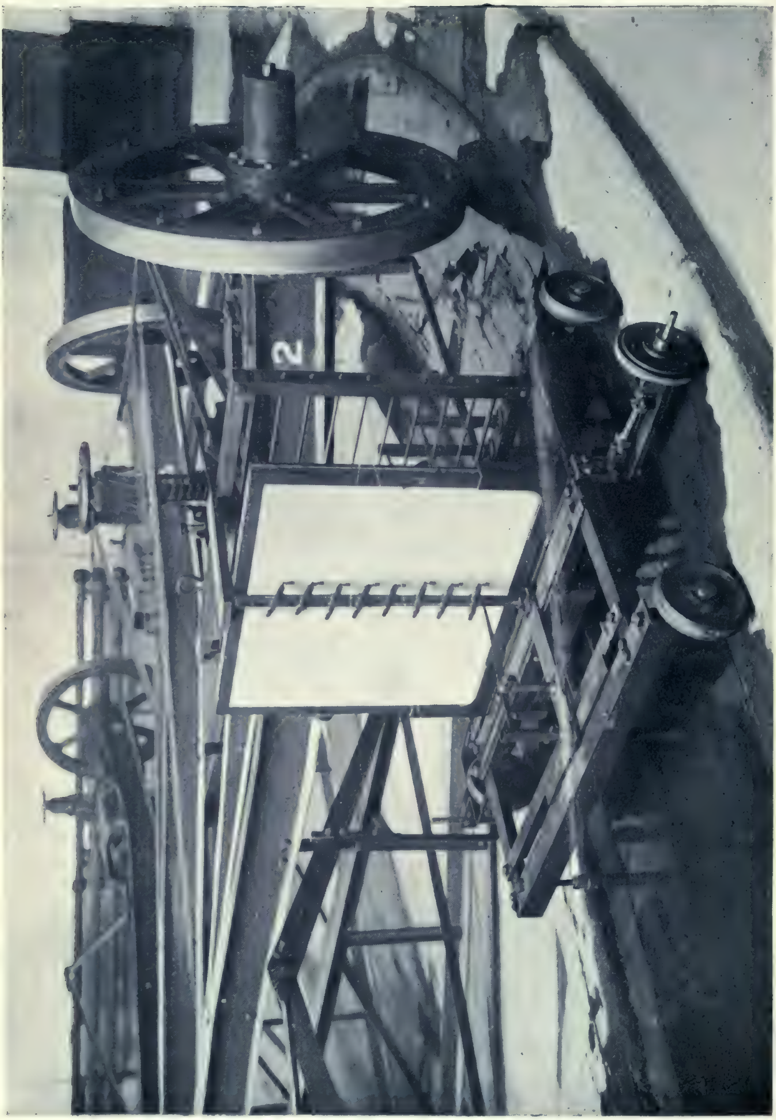


Fig. 5.

each side of which a drawing paper is clamped. At one end of the frame is a series of eight plungers working in guide tubes, and each provided with a small wheel at the lower end. These wheels run on the road surface, one in the track of each of the wheels of the test machine. The plungers are thus forced up and down by the form of the road and the top ends are connected by a system of levers and rollers to pens marking on the paper fixed to the drawing board. The plungers are of different lengths, so that all the eight pens are in one vertical line with 2 ins. of vertical height between each two. The carriage carrying the drawing board is moved at right angles to the road by means of a screwed shaft and nut, the shaft being attached to a friction wheel running on the outer concrete wall of the test road. A series of eight profiles of the road surface are thus traced on the paper as the recorder is drawn round the track. The vertical heights are doubled by the levers, whereas the total length of the road [106 ft.] is represented by a length of 20 ins. on the paper. An example of the curve traced by one pen is given in Fig. 5. The piece of paper on the other side of the drawing board is utilised for taking a series of eight cross profiles of the road surface. In order to draw these, a sliding carriage is provided with one plunger ending in a wheel and has mounted upon it a lever system and guided pen which traces upon the paper. It also carries a gear wheel which gears with two fixed racks, one on the frame and the other on the drawing board carriage. When the sliding carriage is pulled across the frame, the plunger wheel follows the cross profile of the road and the pen draws upon the drawing board paper. The gearing is so arranged that the drawing board is moved in the same direction as the pen carriage, but by half the amount. The actual horizontal length of the diagram is thus half the total width of the track, while the vertical displacement is doubled by the lever.

Unfortunately the Great War temporarily put a stop to these experiments and investigations, but it is to be hoped that they will be renewed under the new Ministry of Ways and Communications which has been established.

Teddington Road Testing Machine. Apparatus for Measuring Waves.



Teddington Road Testing Machine. Apparatus for Measuring Waves.

Road Board "Directions".—In the year 1913, the Road Board issued some "General Directions for Strengthening and Surfacing an Existing Road, with Steam-rolled, Water-bound Macadam".[1] The general tenor of these directions may be given shortly as follows:—

Before proceeding with the work attention should be given to the following points, and careful records kept for future reference. The relative levels of the intended road surface and that of the adjoining lands. The means of disposing of surface water by drainage. The nature of the fences. The width of the carriage way and the full width between fences. The gradients of the road. The character and condition of the existing carriage way and indications of any special features of weakness or wear. The cross-section of road from fence to fence. The material most readily obtainable, either locally or by importation from other districts, and whether the use of imported stone would not be more economical than local stone, even if the initial cost be greater. The requirements as to foundations, and lastly, as to whether it is desired to have footpaths on one or both sides of the road.

Having settled these preliminaries, the following recommendations are then given:—

(1) Before laying the new surface the thickness of the old crust, including the foundation, should be ascertained by opening the road at such places as may be necessary, extending from the side to the centre of the road, such trenches to be made alternately on opposite sides of the road. A careful record of the facts disclosed by these trenches should be kept with plans and sections for future reference.

(2) It is most important that the crust of the road [which expression includes the foundation] should be adequate, and especially that the haunches should be strong enough to afford lateral support to the road, and in all cases of heavily trafficked roads, before laying down a new surface coating, the haunches should be strengthened and the crust thickened, where necessary, either with stone of any kind suitable for bottoming work,

[1] Published by Waterlow & Sons, Ltd., London Wall, London, E.C.

broken to a gauge of from 3 ins. to 4 ins., or with hard core, clinkers, or other suitable materials, according to the nature of the sub-soil. In some cases, where the surface of the broken stone after being steam-rolled is sufficiently smooth for the purpose of traffic, it may be possible to allow the bottoming material to be used as the wearing surface of the road for a short period, not exceeding twelve months, if it is important for financial reasons to postpone for that period the laying down of the final surface coating in accordance with the other provisions contained in these general directions.

(3) Where there are any special circumstances which render it necessary to put in a new foundation the following method should be adopted. The road should be excavated to a depth varying from 9 ins. to 15 ins. according to the nature of the sub-soil and the traffic using the road. The foundation, which should consist of rubble, slag, clinker, or other suitable material, should then be laid and the interstices filled with small material. After consolidation by rolling the foundation should have a cross-fall of 1 in 24. Where the wearing surface is to be of first-class material it is desirable that a coating of second-class stone, such as limestone, flint, etc., broken to suitable sizes, should be spread on the foundation material and rolled to a consolidated depth of about 3 ins. before the wearing surface is applied. The wearing surface should then be applied in the manner described hereafter.

(4) Even when there exists a good natural foundation, the total thickness of the road-crust, including the old and the new macadam after consolidation by rolling, should not be less than 4 ins. In the case of well-drained sub-soil, which cannot be materially softened by the infiltration of surface water, the total thickness, including the new consolidated surface coating as well as the sub-crust and foundations [if any] should not, under ordinary circumstances, be less than 5 ins. In the case of fairly hard clay or other yielding sub-soils, the total thickness, including foundations, should not be less than 9 ins. In the case of soft wet clay or bog or marshy sub-soil special means are to be adopted. Good results can be obtained in some

cases by supporting the road crust on a layer of dry ashes or clayey gravel, or by spreading heather or faggots, but in each case local circumstances and conditions must determine the means to be adopted.

(5) The thickness of the new surface coating of macadam when consolidated by rolling should be about 3 ins., or slightly more where limestone or similar stones are used. If it is desired that the new coating should have a greater thickness when consolidated, the stone should be applied in two coatings separately rolled.

(6) The finished surface should have a cross-fall of 1 in 24 or ½ in. to the foot. If the old crust is not sufficiently thick at the crown to enable this cross-fall to be obtained when a new coating of the thickness above-mentioned is super-added, the old surface should be left intact and unscarified, and the thickness of the new coating of macadam should be increased as far as may be necessary. If the crust is of ample thickness, but the cross-fall excessive, it should be reduced by scarifying the surface and removing material from the crown to the sides previous to the application of the new coating. The material so loosened by scarifying should be screened, and all material finer than ½ in. should be put on one side to be used for top dressing during rolling operations.

(7) The road stone for the new surface coating is to be clean and free from all extraneous matter, of approved quality, broken as cubically as possible, and for normal traffic the size should comply with the British Engineering Standards Committee's standard for 2-in. stone.

Where a road has to carry heavy axle loads, it is desirable that the size of soft stones, such as limestone, should be slightly increased.

Broken stone, specified as 2-in. gauge, shall all pass through a 2-in. ring and shall consist of the following percentages by weight: not more than 15 per cent. passing through a 1½-in. ring in every direction, not less than 65 per cent. over 1½ ins. and not exceeding 2½ ins. in greatest length by measurement, not more than 20 per cent. over 2½ ins. in greatest length.

Broken stone, specified as 2½-in. gauge, shall all pass through a 2½-in. ring and shall consist of the following percentages by weight: not more than 15 per cent. passing through a 2-in. ring in every direction, not less than 65 per cent. over 2 ins. and not exceeding 3 ins. in greatest length by measurement, not more than 20 per cent. over 3 ins. in greatest length.

The screenings obtained by the use of a ¾-in. rod screen during the process of breaking should be kept separate and used as a top dressing during rolling operations.

(8) The stone must be spread by careful men selected for their knowledge and experience of such work, as the durability and evenness of wear of the surface obtained by steam-rolled coatings greatly depends on uniform spreading. The whole of the stone should be turned over in the process of spreading. Care must be taken not to allow the stone to be tipped upon the road close to the point of spreading, as this prevents a thorough turning over of the material in the act of spreading.

NOTE.—One ton to cover 9 sq. yds. may be taken as an average quantity required to give a consolidated thickness of 3 ins. The term "stone" includes all material broken to macadam size used for surfacing purposes.

When stones are spread in thick coatings so that 1 ton covers less than 9 sq. yds., there is a greater liability to unequal consolidation, inasmuch as stones are pushed in front of the roller until the roller surmounts them and thus a corrugated or wavy surface is formed.

(9) The rolling should in most cases be carried out by a roller of a weight of about 10 tons. This must be in charge of a skilled driver who has been specially trained for the purpose. The macadam should be consolidated by starting the work at the sides and gradually working towards the centre. No water or binding should be applied until dry rolling has been carried out to a sufficient extent to form a smooth, hard surface, with the correct cross-fall, with the stones well knit together and presenting a mosaic surface. The cross-section of the newly rolled surface should be frequently checked by the use of a template, or long straight-edge and level, to ensure that the cross-fall of 1 in 24 is

correctly obtained. No spreading or rolling is to be carried out in frosty weather. When the road cannot be entirely closed to traffic care should be taken to, where practicable, minimise inconvenience to the travelling public during the progress of the work by coating one-half of the width at one time. In order to ensure a good joint in the centre of the road care should be taken that the roller, when rolling the first half, should leave at least one foot of unrolled stone in the centre of the road until the other half has been re-surfaced, when the rolling of the whole can be finished. The unrolled portion should be lightly rolled before dark, as no unrolled stone should be left on the road overnight. Care should be taken not to leave a vertical or steep edge of the new coating, but the edge should be thinned out so as to afford an easy passage from the new coating to the old surface. Notice boards warning the public that steam rolling work is in progress should be placed at reasonable distances from each end of the work.

(10) The binding material should be the best reasonably obtainable. It should be either of the same material as the new coating, or of granite, limestone, or slag chippings, or failing these, suitable pit gravel, and the largest stone in it should not exceed $\frac{3}{4}$ in. in its greatest dimension. The binding material is not to be applied until the stones have been tightly rolled as above described. It should then be spread, watered, and swept over the surface during the final rolling operations, working it from the channels towards the centre so as to fill the interstices or voids between the rolled stones. Care should be taken not to use more binding material or water than is absolutely necessary to ensure proper consolidation. The use of a small proportion of clean and well-weathered road scrapings is permissible, but the utmost care is required to prevent the use of road scrapings of unsuitable quality or in excessive quantity. The success of water-bound steam rolling so greatly depends on the quality and quantity of the binding material used that extreme care should be taken in its selection and application.

(11) In some cases it is advisable that a steam-rolled water-

bound macadam surface should be lightly watered and re-rolled from a week to a fortnight after the first rolling.

(12) A careful daily record should be kept of all particulars of the work, the number of men employed, the time occupied, the quantity of material used, the area of new coating finished, and also of the state of the weather and other details.

The above "official" instructions are thoroughly practical, and if adhered to, in the construction of a water-bound macadamised road, should lead to good results.

The next question to be dealt with will be that of—

Road Rolling.—There is no doubt that formerly the rolling of road metal into place was frequently done in a very perfunctory manner, without skill, and generally with rollers that were far too heavy. It was quite usual then to roll 1,500 sq. yds. of newly laid metal in a day, or even more, whereas now it is very unusual to roll more than 500 sq. yds. a day, and with a much lighter roller than was formerly used.

Slow and Light Rolling.—This slower and lighter process tends to greater consolidation and less movement amongst the stones, and also in great measure to prevent the setting up of the wavy surface of the road which is so apparent in roads that have been hastily and improperly rolled. This waviness of the road surface has lately much exercised the minds of highway engineers and others, and various causes have been assigned to this evil, for when once it is set up the tendency is naturally to increase under the traffic as the wheels fall with more or less violence from the crest to the hollow of the wave, thus deepening the hollows. Such a road is not only unpleasant to travel on, but it also soon gets out of repair. This question of waves and corrugations will be dealt with in a succeeding chapter.

Ramming instead of Rolling.—In this respect it would no doubt be better if a machine could be introduced to stamp or ram the metal of a road into place instead of rolling it in, but hitherto experiments in this direction have not proved very successful.

The Ross "Ramming" Machine.—The illustration shows an attempt by an American engineer of the name of Ross, who, about fifty years ago, patented this machine, but the author is not aware whether it was ever tried anywhere or with what success. This machine is said to have weighed 20 tons, and this alone would be detrimental to its use. The rams or beaters were actuated by cams somewhat on the principle of the early ore crushers; they were five in number, and were stated to give an effective blow of about 3 tons for each ram. The lower part of the frame acted as a water-tank. There appears to be much room for improvement in the design, but it is given as an example of efforts which have been made in this direction, and also as being of some "historical interest".

There can be no doubt that road rolling is still carried on in rather a crude and unscientific manner. It is evident that in the first stage of rolling the metal is in a loose condition, and is liable to considerable attrition, and also to crushing, if too heavy a pressure is applied at first, whereas the final rolling should be of a heavier pressure in order to thoroughly bind, and compress, the metal into place, so as to form a road that will be able to withstand the heaviest vehicular load that is likely to use it. This is sometimes attempted with a water-ballast roller, but as water is not always procurable in rural roads, there is some difficulty in securing that the above method of rolling shall be employed.

Petrol-driven Rollers.—The illustration is a type of petrol-driven water-ballast motor roller manufactured by Messrs. Barford & Perkins of Peterborough.

The weight of the roller is 6¾ tons when empty and 8½ tons when full of water. The front roller cylinders are 4 ft. wide by 3 ft. diameter and the rear roller cylinder is 4 ft. in width by 3 ft. 6 ins. in diameter. The water-tank is seen at the rear of the roller. Such a roller can be made of any weight suitable for the work in which it is to be employed and is merely given as a type.

The Pickering Roller.—Mr. J. S. Pickering, M.Inst.C.E., the Borough Engineer of Cheltenham, designed a roller in 1908, which is constructed and supplied by Manns Patent Steam Cart and Waggon Co. of Leeds, of which the illustration below is a drawing and description.[1] The length of this roller, over all, is 12 ft. and the width 5 ft.

The rolling wheel, which is placed at the rear and on which the bulk of the load is concentrated, is 3 ft. 6 ins. wide and 3 ft. 6 ins. in diameter. A water-tank of 200 gallons capacity

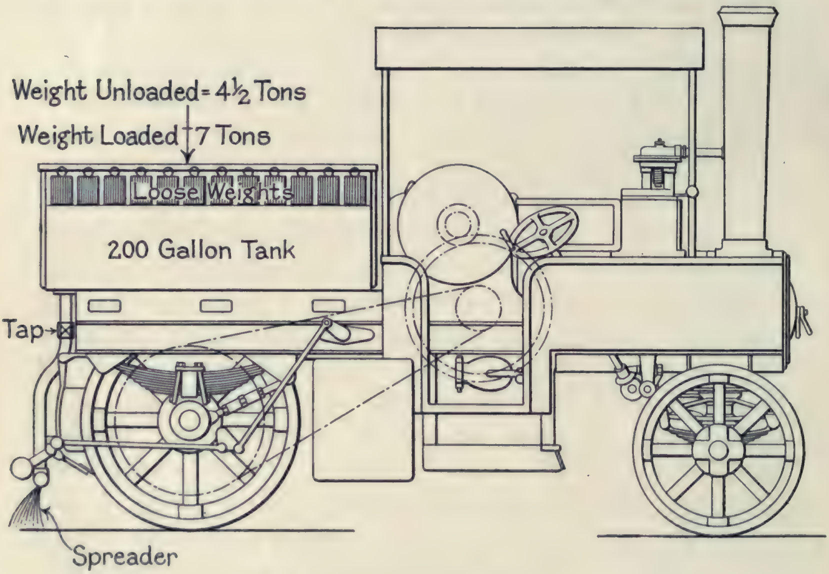
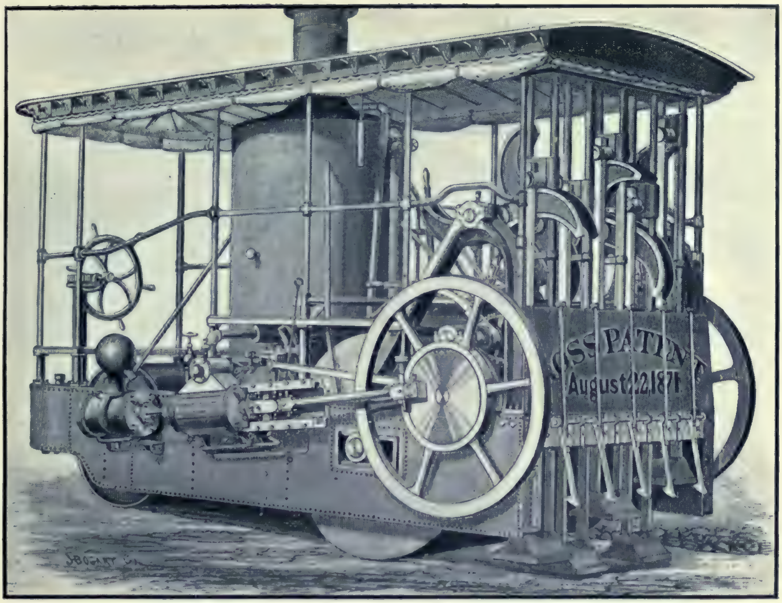


FIG. 6.—The Pickering Roller.

is placed over the rolling wheel, the water being distributed behind through a perforated pipe 3 ft. wide. The distributor is divided at the centre so that a spread of either 18 ins. or 3 ft. may be given. The top of the water-tank is formed into an iron box in which cast-iron blocks are placed to enable the weight on the rolling wheel to be adjusted to the work it is required to do. The following are the weights of the machine under different conditions :—

[1] *See* Report of the County Councils Associations Road Conference, 1909, paper by Mr. Pickering on "The Systematic Patching of Macadamised Roads".



The Ross "Ramming" Machine.

Type of "Petrol-driven" Roller.

"Crompton" Three-axle Roller.

	Tons.	Cwts.	Qrs.
Weight on rolling wheel without added weights and with water-tank empty	4	7	1
Weight on rolling wheel with tank full of water, but without added weights	5	6	1
Weight on rolling wheel with added weights and with water-tank empty	5	18	3
Weight on rolling wheel with tank full of water and added weights	6	17	3
Total weight of machine without added weights and with water-tank empty	6	19	2
Total weight of machine with added weights and tank full of water	9	10	0

Mr. Pickering was public spirited enough not to patent this roller, which has proved to be exceedingly useful in Cheltenham as well as other places. He also uses the roller for tar spraying by fixing a 500 gallon tar tank on it with a distributor attached, the tar being heated to the required temperature by means of a steam coil circulating from the boiler and a coke fire underneath. After the spraying is finished and the road has been gritted, the roller is used for rolling it in. One of the great advantages claimed for this roller is that it reverses very easily and consequently can be used for "patching," with marked success; it is stated that it can travel over a single small patch no less than thirty times in a minute. The great trouble, however, with all petrol-driven rollers is that they are alleged to be difficult to start after stopping on a road which they are engaged in rolling. This is said to be due to the want of reserve power which exists in a steam-driven roller. The question of patching will be referred to later, but, whilst dealing with rollers, it would be well to refer to the "Crompton-Tapp" patent "Three-axle Roller". As has already been stated, the question of waves on the surface of a carriage way has exercised the minds of road engineers for some time, and various causes for their formation have been suggested. In the year 1913, Colonel R. E. Crompton, C.B., M.Inst.C.E., read a paper before the Institution of Mechanical Engineers on "Mechanical Engineering Aspects of Road Construction," in which he stated, *inter alia*, that he believed that as "rolling is carried out in the direction of the line of traffic, however skilfully the operation of rolling is performed, it always produces waves which are eventually intensified by the traffic, for when an ordinary two-axle roller is first brought on to newly spread road material it alternately pushes the material forward, until a certain resistance to forward movement is encountered, and then rolls over the accumulation thus formed in front of it". The waves thus formed serve as a "starting-point for the shorter period waves eventually formed by the traffic itself".

Crompton Three-axle Roller.—To avoid this assumed action of the ordinary roller, Colonel Crompton designed a three-axle roller which is now manufactured by Messrs. Barford & Perkins of Peterborough, of which Plate VI. is a photograph and description.

The roller consists of three roller cylinders carried on three axles attached to a rigid frame, the driving or centre axle only being spring mounted. The motion of the centre axle upwards is limited by stops which can be brought into action as required, the roller being then free to fall below, but not to rise above, an adjustable fixed point relative to the two end rollers. Adjustment of this point and variation in the distribution of the weight on the three axles is carried out by means of a special form of screw adjustment operated by a hand-wheel.

The total weight of the roller in light running order without water-ballast is about 10 tons; with water-ballast in the rollers and a full tank the total weight can be increased up to 11½ tons, the weight being so distributed that at no time is the weight on the front roller less than 17 cwts. in excess of that on the rear roller, this being necessary to prevent both front and rear steering rollers leaving the ground.

By the hand-wheel adjustment already referred to, the distribution of the weight over the three axles can be varied between the following limits, viz. :—

Front Axle. Tons.	Front Axle. Cwts.	Centre Axle. Tons.	Centre Axle. Cwts.	Rear Axle. Tons.	Rear Axle. Cwts.	
1	3	8	17	—		without water ballast.
3	13	3	8	2	11	
1	3	11	0	—		with water ballast.
4	10	4	2	3	13	

this variation in axle-weights giving corresponding rolling pressures varying from 160 lbs. per inch of width up to 400 lbs. per inch of width without water-ballast, and up to a maximum of 500 lbs. per inch of width with water-ballast and a full tank.

It is claimed that this adjustable variation of rolling pressure enables a roller of this type to carry out work which previously required one light and one heavy roller, and also makes it very suitable for rolling newly spread, and consequently very plastic, asphaltic, or tar macadam surfacing material.

It is also stated that for this work the best results are obtained by adjusting the centre roller slightly below the other two, so that the weight is evenly and suitably distributed when the front roller first comes on to the unrolled material, and afterwards causes a heavier compression beneath the central roller every time it is run back on to the partly consolidated road surface. This results in the roller automatically causing the material to receive gradually increasing compression as it cools down and hardens.

The use of the stops which prevent the centre spring-mounted roller rising above a pre-determined point in relation to the end rollers prevents the formation of harmonic waves in the rolled surface, as in passing over the ridge or crest of a wave increased pressure is automatically brought to bear on the road surface at this point by the centre roller, forcing the surfacing material down into the hollow or depression, over which, by virtue of the spring action, the roller then passes with a decreased rolling pressure. The production of harmonic wavy surfaces is still further obviated by unequal spacing of the three axles, the distance between centres of the front and centre axles being greater than the corresponding distance between centres of centre and rear axle.

Steering of the front and back rollers is effected simultaneously by worm gearing of the correct ratio, and no difficulty is found with steering even under the hardest working conditions. Unfortunately the roller was petrol driven, and consequently suffered from the same defect already mentioned with regard to this type of engine.

Whether this roller would perform all that is claimed for it in the above statement, if steam driven, may be a matter for argument, but the attempt to improve upon the present rather crude method of consolidating road crusts by rolling is certainly worthy of encouragement.

With regard to the method of rolling in the ordinary manner, the following extracts are given from the "Instructions to Roadmen," issued by Mr. J. A. Bean, the County Surveyor of Northumberland, which relate to rolling:—

"**Steam Rolling.**—*Binding.*—Some time before the steam roller is due on a section, and when chippings are not available, the roadman must prepare at convenient places on the road margin, or in depots, a sufficient quantity of binding material such as sand or road scrapings so that no time may be wasted while the roller is at work on the section. About one cubic yard of binding material is required for 10 cubic yards of stone.

"*Water.*—He must also ascertain where water can be conveniently procured.

"No stone must be laid on the road until the roadman knows that the roller is at hand, and the surface of the road must be thoroughly scraped and cleaned before any metal is spread.

"*Scarifying.*—Where the road is very hard, and the weather is dry, the surface should be scarified before any material is spread; very little binding will be required after scarifying. Where the surface is uneven the ridges must be picked up and the hollows filled. The new material is then to be spread evenly over the surface.

"The roller is to be passed twice or thrice over it before any binding or water is put on.

"After this the binding is to be put on *sparingly*, and the whole well watered.

"*Rolling.*—The rolling must be continued working backwards and forwards gradually from the sides to the centre, sufficient water being added from time to time to make the binding sloppy. While the rolling proceeds the material is to be continually swept so that the slurry is carried evenly over the material, and all interstices filled with it.

"*Consolidation.*—When the whole is thoroughly consolidated, and the surface is quite compact and solid, all surplus binding and water must be swept off.

"*Accounts.*—The chargeman must keep a record of all labour employed in connection with the work, and at the close of each day fill up and forward the "Steam Rolling Daily Statement" to the Divisional Surveyor.

"*Tools.*—The chargeman will be responsible for the proper use and control of all tools and brushes employed in connection with the rolling, the property of the County Council.

"*Steam Roller.*—The owner of the engine is responsible for the proper observance of the rules and regulations for working locomotives enacted by 28 and 29 Victoria, chapter 83, and neither the roadman or his assistants shall take any part in the driving or conducting of the engine unless special instructions have been given.

"*New Macadam.*—No material, either large or small, must be laid across the full width of the road unless it can be well rolled and covered with binding same day before leaving the work.

"*Half-width Clear.*—Where it is necessary to lay on stone that cannot be rolled in that day, then only one-half of the macadamised roadway shall be covered, the remaining half being left for the traffic; and in any case a clear space of at least 6 ft. must be left.

"*Strangers.*—It is never advisable to have any unconsolidated stone-laying on the carriage way at night, particularly over the week-end, as it is then, more than during the week, that strangers to that particular part of road may drive into same unexpectedly."

The above "Instructions" with regard to steam rolling are thoroughly practical, and should serve as a useful basis on which to frame similar instructions, adapting them to local circumstances.

Before concluding this portion of the book on "Rolling," the following account of the manner in which this work is performed in America may be of interest[1] :—

American Methods.—After the subgrade has been prepared and has been accepted by the engineer, a layer of broken stone of the approved size and quality for bottom course shall be spread evenly over it to such depth that it shall have, when rolled, the required thickness. The depth of the loose stone shall be fixed by laying upon the subgrade cubical blocks of wood of the required size ($1\frac{1}{3}$ times thickness of course to be formed) and spreading the stone evenly to the same thickness.

The roller shall be run along the edge of the stone backward and forward several times on each side before rolling the centre. Before putting on the filler the bottom course shall be rolled until the stones do not creep or weave ahead of the roller. In no case shall the screenings or sand for filler be dumped in mass upon the crushed stone, but they shall be spread uniformly over the surface from waggons or from piles that have been placed on the shoulders. It shall then be swept with rattan or steel brooms and rolled dry. This process shall be continued until no more will go in dry, when the surface shall, if required by the engineer, be sprinkled, to more effectually fill the voids. No filler shall be left on the surface.

The middle course of stone shall be spread on the bottom course to such a depth that it shall have, when rolled, the required thickness. Blocks of wood ($1\frac{1}{3}$ times thickness of course to be formed) shall be used to fix the depth of the loose stone; care shall be taken to preserve the grade and crown. Before putting on the screenings it shall be rolled dry until the stones do not creep or weave ahead of the roller. It shall then be filled with screenings, leaving none on the top, and rolled dry.

The top course of stone shall be spread on the middle course to such a depth that it shall have, when rolled, the required thickness. Blocks of wood ($1\frac{1}{3}$ times thickness of course to be formed) shall be used to fix the depth of the loose

[1] *Vide* "The Construction of Macadamised Roads," by Austin B. Fletcher, Office of Public Works, United States of America.

stone; care must be taken to preserve the grade and crown, also to prevent a wavy surface. It shall then be covered with dry screenings, swept and rolled dry, after which the road shall be sprinkled until saturated, the sprinkler being followed by the roller. More screenings shall be added, if necessary, and the sweeping, sprinkling, and rolling shall continue until a grout has been formed of the screenings, stone dust, and water that shall fill all the voids and shall form a wave before the wheels of the roller. The road shall be puddled as many times as may be necessary to secure satisfactory results.

After the wave of grout has been produced over the whole section of the road, this portion of the road shall be left to dry, after which it shall be opened to travel. Where necessary, enough screenings or approved sand shall be spread on top of the macadam to leave a wearing surface at least three-eighths of an inch thick. This wearing surface shall be maintained and renewed, if necessary, until the whole road has been accepted.

There can be no doubt that the whole question of rolling, the modern method of constructing a bituminous "carpet" on a road surface, requires serious consideration, and this will be dealt with in the chapter on "Bituminous Roads".

Amount of Metal Consolidated. — With regard to the quantity of freshly laid metal that can be consolidated by a roller in a working day, this, of course, varies considerably under the varying conditions which affect the question.[1] The modern practice is to calculate the amount in tons of metal dealt with, and not, as formerly, by the number of square yards rolled, as this latter method of calculation might be misleading without knowing the exact thickness of the metal when freshly laid on the surface of the road. In Buckinghamshire a steam roller rolls about 32 tons of metal during a working day. In Worcestershire the average is stated at 27 tons a day; in other counties the average ranges between 27 to 30 tons a day, but, with gravel, this amount is raised to 40 tons a day.

The late Mr. Thomas Aitken, in his well-known book on

[1] See also page 68.

"Road Making and Maintenance," states that a 10 or 12 ton roller will roll 50 tons and 40 tons respectively in a working day of 9 hours, but he very properly remarks:—

"The quantity of material which a road roller is capable of consolidating in one day will depend on the description of the road stone and thickness of the coating applied, the amount and nature of the binding used, the available water supply, and the time lost by compulsory stoppages for the passing traffic."

He might also have added that the skill and energy, or otherwise, of the driver of the roller should also be taken into account.

Water Required.—The amount of water used on a road to assist in the consolidation of the metal should be as little as possible, preferably not more than about 2 gallons of water for each square yard of surface rolled, but this is, of course, dependent on the quality of the metal and of the amount and quality of the binding employed, but it should, if possible, in no case exceed 4 gallons per square yard.

Binding Required.—With regard to the amount of binding to be used, this depends so largely on local circumstances, the description of the metal, and of the binding itself, that any attempt to give the quantity would be misleading.

There are certain road stones that are much more cementitious than others, and there are certain sands used for binding that contain oxide of iron or lime, which greatly assist in the binding operation, so that it is evident no reliable data can be given on this point. It is evident, however, that the use of an "earthy" binding, or one containing organic or vegetable matter, should be scrupulously avoided for use as a binding material, for although the immediate effect might appear to be satisfactory, the result would eventually prove disastrous. In any case, however, the less binding that can be used, compatible with a properly bound and consolidated road, the better. The important point to be aimed at, in addition to proper consolidation, is that the surface should be well sealed against the entrance of water.

On this point the author cannot do better than give the following extract from a paper given before the Institution of Civil Engineers of Ireland, in April, 1913, by Mr. P. C. Cowan, D.Sc., M.Inst.C.E., the Chief Engineering Inspector of the Local Government Board, Ireland, on the "Improvement of the Main Roads of Ireland," which is as follows:—

"**Road Rolling in Ireland.**—It is of primary importance that the work should be closely supervised by an overseer, and scrupulous care should be directed to the selection of the best materials available. The stones should be evenly broken to a moderate size, not exceeding 2½ ins. in their largest dimensions, and applied in coating from 3 to 5 ins. deep. All stones markedly above or below the size desired should be rejected, as an irregular mixture of large and small stones cannot be made into an evenly-wearing road crust. If stones of a larger size than is above indicated are used it is found that the surface, though apparently satisfactory at first, soon becomes uneven and rapidly deteriorates, especially if the material is hard.

"The coating of broken stones should be first thoroughly rolled dry, and without the slightest admixture of any blinding, though scarifying or wetting the old surface is sometimes desirable in the application of a light coating to a strong, but uneven, road surface. The shape and cross-fall should be kept uniform by the use of templates or straight edges and spirit levels.

"The dry rolling should be continued until the stones show a mosaic appearance, and then, and not till then, the smallest quantity of blinding should be applied by making up a slurry, like very thin mortar, in the road channel with sharp sand or old road drift or scrapings containing little soft matter, and sweeping it towards the centre, as rolling proceeds, from side to side. The important point to bear in mind is that to secure the best work which will wear well and uniformly in all weathers, practically no blinding material should pass below the top layer of stones. It should merely fill the fine joints secured by dry rolling.

"Large quantities of mud are frequently applied to the unrolled stones with a view to securing a rapid finish, but the resulting road surface is bad, is readily softened by rain, and rapidly becomes uneven on account of the mixture of soft and hard materials. What is required for the best results is a road crust with a minimum amount of soft materials in which all the stones are directly bedded on and supported by other stones.

"It is important that after a road surface has been rolled it should be frequently cross-swept, and any small depressions which show filled up with a very small quantity of finely broken materials. With such attention a coating of moderate depth will last for a number of years without any extensive repairs.

"It has been found that the saving in the cost of materials, surface labour, and the removal of mud is so great, over the period that good steam-rolled coating lasts, that it more than balances the cost of steam rolling on roads with considerable traffic for which a sufficient supply of materials has hitherto been provided.

"It, therefore, appears that with a well-regulated system of steam rolling the great advantage of smooth, clean roads, with minimum resistance to traction and wear and tear of vehicles and horses, can be secured on many important roads without increased cost."

Cost of Rolling.—With regard to the cost of rolling, this must necessarily vary considerably in almost every locality as there are so many disturbing factors to be considered, but in arriving at the cost per ton, or square yard, the following items should be considered :—

The wages of the driver and say two men for sweeping, etc., as the rolling proceeds, the cost of carting and spreading the water, and also that of the binding material, the labour of spreading the binding material, the fuel, oil, and water, used by the roller, depreciation of the roller and plant, watching, lighting, and incidental expenses, if any. Sometimes a proportion of the depot where the roller, etc., is housed and similar expenses are added, so that when returns of the cost of rolling are given it is often difficult to know what items have been included in the cost. From information in the possession of the author as to the cost of rolling in various parts of the country, it would appear that this cost ranged between 6d. and 1¾d. per ton of metal rolled at pre-war prices, which gives a fairly wide margin, as might be expected.

Foundations.—The foundation of the road is known to be of primary importance, but, unfortunately, it is the point which is often the least considered in some of the rural roads of this country; as the expense of taking up an existing carriage way and replacing it with a properly constructed foundation of the well-known Telford type would in many cases absorb money which could be better spent in other directions. The question, therefore, as to whether a better foundation is necessary in any carriage way must be left to the discretion and experience of the road engineer.

Foundation on Bad Soil.—Where there is marshy or treacherous ground, special provision must be made to meet such a case, and the following method adopted by Mr. Hooley, the late County Surveyor of Nottinghamshire, may be studied as a guide in such circumstances:—

"The outside ditches having been thoroughly opened up, the surface of what was practically a jungle-swamp was excavated to the required depth, and the ground shaped to the necessary camber, i.e. a cross-fall to either side of half an inch to one foot; on either side a 4-in. agricultural drain was laid and connected at intervals of about a chain with the side ditches. The ground was steam-rolled solid up to the pipes, and where a swampy piece of ground was met with this was cross-drained by V laid pipes to the sides. Bush fagots were similarly cross-laid in the opposite way to the pipes, and a perfect layer of dry filling or ashes was laid over the whole, making the depth of ashes and bushes about 15 ins. in thickness. This was left to dry and when completed was covered with a covering of 7 ins. in the centre and 9 ins. at the sides over the pipes to the centre of the road with coarse hand-packed, 9 to

7-in., cubes of slag. All the interstices were, as far as possible, packed with finer slag, and the whole was rolled to an even face. [Where slag is not obtainable coarse limestone or any local stone would be sufficient and good if similarly laid]: on the top of this layer of "rejections," slag, i.e. coarse slag of about 3-in. gauge was laid and again steam-rolled. Again all the interstices were filled with coarse screenings with the dust left in, and a face of road was left as the newly termed 'Subcrust' ready for the final surfacing of Tarmac."

Foundation on Ordinary Soils.—For ordinary roads the following method might be applicable: execute the carriage way to the required depth and contour, take out any soft places and fill in with any suitable material, such as stone, clinker, ashes, or any fairly hard and dry material; roll this level and then lay upon the foundation thus formed any suitable material, such as furnace slag, coarse clinkers from engine boilers, etc., 4-in. to 5-in. gauge broken stone, brick bats, or any coarse, hard dry material that can be easily and cheaply obtained. The necessity for a hand-pitched foundation of the Telford type is not always necessary, but it is essential that the foundation of a carriage way should not only be strong enough, but also that it should drain the road. Any road from which water cannot freely escape is greatly handicapped and liable to disintegration.

Necessity for Good Foundation.—What could be more striking as to the necessity for good foundations than that which appears in a memorandum, dated the 17th October, 1916, by Mr. H. T. Chapman, the County Surveyor of Kent, which he laid before the Departmental Committee of the Local Government Board, "to consider the law and regulations relating to the construction and use of road locomotives and heavy motor cars," which contains, *inter alia*, the following paragraph:—

"The main roads of the county generally possess no foundations in the accepted sense of the term, but merely accumulations of broken metal, i.e. flint, ragstone, granite, basalt, or quartzite overlying chalk, clay, and gravel subsoils, and the action of both slow and quick heavy traffic tends to distort and move the surfacings, especially when the subsoil is wet. Moreover, when the crust of metalling is not of adequate thickness, the subsoil under heavy loads, during wet weather, works towards and often through the crust, rendering the roads unstable.

"On the heavily trafficked roads it has become necessary to remove clay for a depth of as much as 18 ins. below the surface, and put in hard-core, clinkers, and other like material to enable the surface metalling to carry the traffic."

Repairs.—A few words on the subject of the repairs of a water-bound macadam carriage way may be useful. There are two schemes of practice with regard to repairs, viz. the "stitch-in-time" school and the "re-surfacing" school, and there has been some controversy as to which method is the right one.

As a matter of fact, both are right, and if proper attention is given to a water-bound macadam road, it will be found that "patching" is not only necessay, but essential for its maintenance, and this precaution applies to every description of road surfacing. When past these slight repairs, it, of course, becomes necessary to re-surface the whole stretch of road.

The French Roads.—The excellence of the French roads for so many years was undoubtedly due to their patching system, which was carried to an extreme of perfection; the "cantonniers," or roadmen, had quite short lengths of road under their charge, and they took a keen pride in keeping their stretch of road as smooth and as clean as a billiard table!

Every loose stone was picked up by hand, and carefully preserved to be properly replaced, and every rut or depression received immediate attention. The surface of the roads of France were thus kept in the most perfect condition at an extraordinay low cost for maintenance, and it was only that they lacked strength of foundation and sufficient thickness of metal that they gave way on the introduction of self-propelled traffic. The French roads were a splendid example of the advantages of the "stitch-in-time" principle, which, however, could not be followed in this country, owing principally to the different labour conditions which exist between the two countries. In France these roadmen lived close to their special length of road, whereas in this country they often live many miles away. Even now, patching is not very scientifically performed in this country, except in a few districts, the metal used for this process being usually put *on* the road instead of *in* it. Thus metal is wasted, and the mending is badly done.

Proper Way of Repairing Roads.—The proper method is, of course, to first carefully scrape off the mud, then to cut out the hole or depression in a rectangular shape, the small amount of metal thus wasted in cutting the sides square being amply compensated by the better shape of the patch; the depth of the excavation should be amply sufficient, and the bottom well hacked to form a key for the new metal. The excavation should then be filled with new metal broken to a gauge of about 1 in., and, if a small patch, well rammed into place, with the addition of some suitable binding and a little water. If the patch is of sufficient size, a light roller should be used instead of a rammer. If the excavation can be slightly undercut, so much the better. Now that so many forms of so-called tar macadam can be easily procured, it is better to use this even in an ordinary water-bound road, as the excavation need not be so deep and binding, and water and labour are saved by the use of this material.

After completion of the patch, with whatever material it is made, it should be dusted over with clean, sharp sand, or other suitable material.

Re-surfacing.—With regard to re-surfacing, or removal of the surface of the road, this, of course, must become necessary in process of time, but as to when this crucial point is reached must depend upon local circumstances.

The method for re-surfacing is practically the same as that for the construction of a new road, and need not be recapitulated. It is essential that all mud should be removed from the surface of the existing road before the new metal is applied, but whether the old surface should be scarified or chequered must depend on circumstances which must be left for local experience to decide. There is, however, a tendency in this country to dispense with labour in favour of material, and "metal" often takes the place of manual labour when the latter could be more economically employed.

In connection with this question of labour as against materials, and the importance of fairly skilled labour watching and attending to the roads in a systematic manner, the author gives the following extracts on "Duties of Roadmen," which were issued by Mr. J. A. Bean, the County Surveyor of Northumberland, to the men in his employment.

Mr. Bean has kindly given the author permission to publish these "Duties" or instructions, which are as follows:—

"**Duties of Roadmen.**—*General.*—The duty of each man in charge of a section of road is to keep it at all times free from loose stones and mud, to attend to the drainage, to keep the footpaths clean and smooth, and the roadside margins at all times level, sound, and free from obstructions to horsemen.

"*Tar Macadam.*—Tar macadam roadways and footpaths should be sprinkled lightly with chippings, sand, or ashes in frosty weather, and the roadman should keep a stock of this material at intervals alongside the road.

"*Footpaths.*—The surface of the footpath should never be more than 3 or 4 inches higher than the macadamised road at the channel. The top of the kerb should be laid so that it is level with the *crown* of the roadway. Where the road is in a cutting a ditch should be formed between the foot of the slope and the footpath to intercept any water coming out of the bank. Before a footpath is covered with ashes or gravel all projecting stones and high places should be picked up and the hollows filled in with hard material.

"*Hills.*—On steep hills the roadway should be sprinkled with chippings, ashes, or sand in frosty weather to prevent horses or waggons sliding, also on the tar macadam; and the roadman must in the autumn provide a sufficient supply of this material to be in readiness.

"*Sod Borders.*—The macadamised part of the road should be defined on both sides with a sod border where there is no kerb. The top of the sod border should be level with the crown of the road. This sod border should be continuous from one end of the section to the other and should be carefully set out with a line, then dressed with a spade. Where the road bends, the sod border should be laid carefully to the sweep of the road so as to form a regular curve. Cross channels must be cut through the sod border or roadside margin, where necessary, to carry the surface water to the back ditches. These cross channels should be the full width of the spade and should be as shallow as possible, and it is most important always to keep them open and free for water to pass from the road. The sides should be sloped off so that they may not form obstacles to horsemen, as deep seughing or channelling is very objectionable.

"Generally the ordinary width of the road between the sod borders should not exceed 18 ft., and on moorland roads a width of 15 ft. is sufficient.

"*Roadside Margin.*—No turf or soil must be removed from the roadside, and it is the duty of each roadman in charge of a section to prevent this, and also to prohibit and report the deposit of soil, landstones, or manure on any portion of the ground between the fences of the road. All holes at the roadside must be filled up so as not to form obstacles to horsemen.

"*Stone Depots.*—Depots for the stone are to be formed by the roadman at the most convenient places. They must always be formed on the dry and solid ground, the bottom of which must be level and covered with a coating of ashes. Each depot must be placed quite clear of the roadway and footpath, and in a place where it will not interfere with the horse track. It is the duty of the roadman to see that no stone is deposited except in the depots, and that it is tipped quite clear of the macadamised roadway.

"*Laying on Stone.*—The chargeman of each section must exercise constant observation over his road, both in wet and dry weather, in order to determine exactly what portions should be re-coated. His object must be to maintain over the whole of his length a crust of hard stone sufficiently strong to bear the traffic and withstand the effects of frost and wet weather, and to form a road with a level and even surface having a regular fall from the crown to the sides. A road 18 ft. wide between the sod borders or kerbs should be 4 ins. higher at the crown than at the sides.

"Before any stone is laid on all small holes and inequalities in the surface to be covered must be levelled, all mud must be scraped off, or if it is dry weather the surface must be slightly loosened with a pick, especially at the outside of the patches.

"The stones must be laid close together one stone thick, the ends of the patches being slightly tapered off and the smallest stones laid at the edges. There must be left between the edge of the patch and the sod border a clear space at least 6 ft. wide, so that the traffic may pass without cutting up the sides of the road or inconvenience to the public.

"On a weak or unsound road small ruts and holes sometimes occur. In such cases the surface round the actual hole should be loosened with the pick and levelled, and then the surface should be coated with new metal. In no case must a single shovelful of stones be placed in a hole or rut and no patch must cover an area of less than two yards by half a yard in width.

"*Binding.*—Whinstone or limestone chippings should be used for binding material, and must be put on very sparingly. Where this is not available sharp sand or gritty road scrapings may be used. No turf, sods, earth, or clay must in any case be laid on, as all these materials make the road rotten and more liable to be injuriously affected by frost, wet weather, or motor car wheels. It should be remembered that whatever binding is put on will give extra labour, as it will soon work up as mud and have to be scraped off.

"On steep hills particular care must be taken to form and maintain a regular surface, with a fall from the crown to the sides sufficient to throw the water freely to the channels.

"*New Macadam.*—The material for the top coating of a road must be broken into cubes of uniform size of 2½ ins. The roadman must see that the heaps are not tampered with, and report to the Surveyor any irregularities.

"After any macadam has been laid on and rolled the roadman must pay constant attention to it until it is thoroughly set. Detached stones must be at once removed.

"*Loose Stones.*—When dry weather commences, say in May or June, the roadman shall pick off by hand all loose stone and place it in heaps clear of the road. It must be re-broken before being used again.

"*Road Scrapings.*—As a rule it is an unnecessary and objectionable practice to heap road scrapings. They should be scattered over the roadside margin which may thus be levelled and improved.

"Where, however, they are not required for this purpose they must be placed clear of the macadam and carted away as soon as possible. In no case must any heap of road scrapings be allowed to remain overnight on the macadamised road.

"*Bridges, Culverts, etc.*—The chargeman shall regularly examine all bridges, culverts, retaining walls, protection fencing, drains, and catchpits on his section, and shall keep them in good order. In the event of any serious damage occurring to any structure, fence, or drain, the property of the County Council, he shall immediately telegraph to the County Surveyor and also the Divisional Surveyor. He shall also send detailed information upon the matter by letter to the County and Divisional Surveyors by post on the same day.

"*Gullies and Drains.*—Special, careful, and regular attention must be given to all gullies, drains, and culverts. They must be kept properly cleansed and clear of all obstructions so that they will not be choked up immediately any heavy rain occurs. Any silting up of the outlets of drains or natural water courses on adjoining land must be reported at once to the Surveyor.

"*Encroachments, etc.*—It shall also be his duty to report to the County and Divisional Surveyor any encroachment that takes place on his section, or when any new houses, buildings, or fences are proposed to be or are being erected adjoining the main road, or when any old buildings or constructions are pulled down.

"*Nuisances.*—The roadman must report at once to the

County and Divisional Surveyor any deposit of manure, lime, trees, stones, timber, building, or other material between the fences of the road.

"*Hedges and Ditches.*—It is the duty of the occupiers of land adjacent to the main road to cut, prune, and plash the roadside hedges, to lop the branches off overhanging trees, and to cleanse and scour the side ditches. In the event of this duty being neglected the chargeman is to report the matter to the Divisional Surveyor.

"*Water Troughs.*—Regular attention must be given to drinking-water troughs to see that they are clean and that no deposit is in them, and that the supply is not in any way contaminated. Attention must also be given to the road near the trough to keep same dry and well drained. Also that no interference takes place with the supply of water, and to report to the Divisional Surveyor if such should be the case.

"*Contours.*—The chargeman must remember that the object of his work is to form and maintain a sound crust of hard metal on all parts of the road impervious to the effects of frost and water, and of sufficient thickness and strength to bear the traffic, with a surface at all times quite smooth and even so that the draught or wear and tear of horse flesh may be as small as possible.

"*Penning.*—Where any penning is being done to the roadway or sides of the existing carriage way, each day's work must be complete in itself, and be covered with small broken material or scars and well rolled before leaving it overnight. When this is done a watchman and lights must be provided to warn the traffic.

"The stones must be hand-packed, each stone being placed upon the broadest base and not made to lean upon another.

"*New Macadam.*—No material, either large or small, must be laid across the full width of the road unless it can be well rolled and covered with binding same day before leaving the work.

"*Half Width Clear.*—Where it is necessary to lay on stone that cannot be rolled in that day, then only one-half of the macadamised roadway shall be covered, the remaining half being left for the traffic; and in any case a clear space of at least 6 ft. must be left.

"*Strangers.*—It is never advisable to have any unconsolidated stone-laying on the carriage way at night, particularly over the week-end, as it is then, more than during the week, that strangers to that particular part of road may drive into same unexpectedly."

There are also many other useful instructions with regard to snowstorms, the fixing of motor caution posts, what to do under the Workmen's Compensation Act, etc., as also with regard to scarifying and rolling, which need not be recapitulated.

Altogether, these "Instructions" are very practical, and could be usefully employed by surveyors who have roads under their control, modified, of course, to suit local requirements.

Amount of Metal Required.—As to the quantity of metal required for re-surfacing a carriage way, this, of course, depends on the thickness to which the stones are laid and also on the weight or specific gravity of the selected stone. A thickness of 3 ins. consolidated is generally found to be sufficient, and this depth can be rolled in one operation, any greater depth should be rolled in two layers in order to ensure proper consolidation. In order to assist in determining how far a ton of any given stone will spread on a road, it has been ascertained that the percentage of voids in broken road metal vary according to the gauge to which the stone has been broken, and that this percentage of voids is as follows:—

Gauge.	Voids.	Solid Stone.
1 in.	48 per cent.	52 per cent.
1½ "	49 "	51 "
2 ins.	50 "	50 "
2½ "	51·5 "	49·5 "

and the following table gives the weights of a cubic yard of broken stone with varying specific gravities;—

Specific Gravity.	Weight of a Cubic Foot.	Weight of a Cubic Yard of Broken Stone.		
		Tons.	Cwts.	Qrs.
3·40	212 lbs.	1	5	2
2·95	184 ,,	1	2	1
2·90	181 ,,	1	1	3
2·70	168 ,,	1	0	1
2·65	165 ,,	0	19	3

In transit the broken stone naturally shrinks in bulk, so that the above weights of a cubic yard would not be quite accurate at the end of the journey. When rolling with ordinary consolidation it may be generally assumed that the original thickness of the metal as spread on the surface is reduced to about 65 per cent.

Method of Ascertaining Voids.—A very simple method of ascertaining the amount of the voids in broken stone was suggested by Professor Ira O. Baker of the University of Illinois, viz. to determine the weight of water which a given vessel will contain, then fill the vessel with broken stone, and determine the weight of water that can be poured into the interstices or voids of the broken stone. The ratio of the first amount of water to the second is the proportion of voids. The operation should be carried out quickly so as to prevent any error due to the absorption of water by the stones.

To Ascertain the Denseness of an Aggregate.—In order to determine the densest practicable mixture of broken stone Mr. Prévost Hubard, the well-known American road expert, suggests the following method: Have two boxes, one to hold an exact cubic foot of broken material and the other to hold 6 cubic feet. Then a total of 6 cubic feet of material can be measured out in any desired proportion by means of the smaller box and thoroughly mixed. This mixture is then placed in the 6 cubic feet box and its depth noted. The mixture showing the lowest depth is, of course, the densest.

Sizes of Broken Stone.—The British Engineering Standards Association took up the question of the sizes of broken stone and chippings suitable for road construction, and delegated a Sectional Committee to investigate the matter.

This Committee was of a very representative character. The report of this Committee was duly published, and is very interesting. In the Preface it is stated that the Committee adopted the term *gauge* to designate the standard group of sizes into which broken stone is divided, while the term *size* has been used for the sub-division of the gauge. In determining the standard gauges of stone, the Committee assumed that the bulk of the material would be of the size desired, but that there must be some allowable deviations, and that allowances should be made with regard to the "most desired size," as, for instance, in the case of 2-in. broken stone, a stone now being supplied from several quarries as 1½-in. gauge, fully complies with the requirements of the standard 2-in. gauge.

The standard specification, amongst other things, fixed the sizes or "standard gauges" of broken stone at 3-in., 2½-in., 2-in., and 1½-in. gauge.

With regard to the 3-in. gauge, it shall "all pass through a 3-in. ring, and shall consist of the following percentages by weight":—

Not *more* than 15 per cent. passing through a 2½-in. ring in every direction. Not *less* than 65 per cent. over 2½ ins., and not exceeding 4 ins. in greatest length by measurement. Not *more* than 20 per cent. over 4 ins. in greatest length by measurement.

With regard to the 2½-inch gauge, it should pass as before through a 2½-inch ring, with the following percentages:—

Not *more* than 15 per cent. passing through a 2-in ring as before. Not *less* than 65 per cent. over 2 ins., and not exceeding 3 ins. in greatest length by measurement. Not *more* than 20 per cent. over 3 ins. in greatest length by measurement.

With regard to the 2-in. gauge, it should pass as before through a 2-in. ring, with the following percentages:—

Not *more* than 15 per cent. passing through a 1½-in. ring. Not *less* than 65 per cent. over 1½ in., and not exceeding 2½ ins. in length. Not *more* than 20 per cent. over 2½ ins. in length.

As to the $1\frac{1}{2}$-in. gauge, it should pass as before through a $1\frac{1}{2}$-in. ring, and the percentages are:—

Not *more* than 15 per cent. passing through a 1-in. ring. Not *less* than 65 per cent. over 1 in., and not exceeding 2 ins. in length, and not *more* than 20 per cent.

Arrangements were suggested for the testing of the broken stone by means of certain apparatus, consisting of metal plates cut with the necessary holes and slots for measuring the sizes, a diagram or drawing of which is bound up with the standard specification.

Stone chippings were also dealt with in the specification of the following fixed gauges, viz. 1 in., $\frac{3}{4}$ in., $\frac{1}{2}$ in., $\frac{3}{8}$ in., $\frac{1}{4}$ in., and $\frac{1}{8}$ in.

The 1-in. chippings must all be capable of passing through a square hole of 1-in. side, and at least 70 per cent. by weight must be retained by a sieve having square holes of $\frac{3}{4}$-in. side.

Three-quarter-inch chippings must all be capable of passing through a square hole of $\frac{3}{4}$-in. side, and at least 70 per cent. by weight must be retained by a sieve having square holes of $\frac{1}{2}$-in. side.

Half-inch chippings must all be capable of passing through a square hole of $\frac{1}{2}$-in. side, and at least 70 per cent. by weight must be retained by a sieve having square holes of $\frac{3}{8}$-in. side.

Three-eighth-inch chippings must all be capable of passing through a square hole of $\frac{3}{8}$-in. side, and at least 70 per cent. by weight must be retained by a sieve having square holes of $\frac{1}{4}$-in. side.

Quarter-inch chippings must all be capable of passing through a square hole of $\frac{1}{4}$-in. side, and at least 70 per cent. by weight must be retained by a sieve having square holes of $\frac{1}{8}$-in. side.

One-eighth-inch chippings must all be capable of passing through a square hole of $\frac{1}{8}$-in. side, and at least 70 per cent. by weight must be retained by a sieve having square holes of $\frac{1}{16}$-in. side.

For testing chippings it is suggested that an average sample, not less than 100 lbs. in weight, selected from the bulk, and fairly representing the consignment, shall be tested on circular hand sieves, 20 ins. in diameter, with square mesh of wires of annealed charcoal iron, of which the thickness or standard wire gauge is given as follows :—

1 in. × 1 in. Mesh.	No. 9 S.W.G.
$\frac{3}{4}$,, × $\frac{3}{4}$,, ,,	,, 9 ,,
$\frac{1}{2}$,, × $\frac{1}{2}$,, ,,	,, 11 ,,
$\frac{3}{8}$,, × $\frac{3}{8}$,, ,,	,, 12 ,,
$\frac{1}{4}$,, × $\frac{1}{4}$,, ,,	,, 13 ,,
$\frac{1}{8}$,, × $\frac{1}{8}$,, ,,	,, 15 ,,
$\frac{1}{16}$,, × $\frac{1}{16}$,, ,,	,, 17 ,,

Trade Names of Stones.—Finally, the Committee gave, as an Appendix, the following list of road stones as a guide to the trade names, which had been, until then, somewhat loosely used, and were not very generally understood :—

Nomenclature of Road Stones.—The following list of trade names is suggested for adoption; the various rocks to be placed under each heading to be left to the decision of the Department of H.M. Geological Survey and Museum of Practical Geology :—

TRADE NAMES OF ROAD-MAKING ROCKS.

Granite.	*Basalt (including Basaltic Whinstone).*[1]	*Grit.*
Gabbro.	*Hornfels.*	*Limestone.*
Porphyry.	*Schist.*	*Flint.*
Andesite.	*Quartzite.*	*Artificial.*

A preliminary list of rocks placed under their respective trade names is herewith submitted :—

[1] It is recognised that the term "Whinstone" is often loosely used in connection with rocks which are not of a basaltic nature. The Committee consider that this is undesirable, and recommend that the term "Whinstone" should be strictly confined to those rocks which come under the trade heading of basalt, and that those rocks which are not strictly speaking of a basaltic nature shall cease to be called Whinstone and shall be classified under their proper heading.

Granite.	*Basalt (including Basaltic Whinstone).*[1]	*Grit.*
Aplite.	Basalt.	Arkose.
Diorite.	Diabase.	Breccia.
Gneiss.	Dolerite.	Conglomerate.
Granite.	Epidiorite.	Greywacke.
Granulite.	Greenstone.	Grit.
Pegmatite.	Lamprophyre.	Sandstone.
Syenite.	Spilite.	Tuff.
	Teschenite.	
Gabbro.	*Hornfels.*	*Limestone.*
Gabbro.	Hornfels.	Dolomite.
Norite.	Hornstone.	Ironstone.
	Mylonite.	Limestone.
	Hornblende schist.	Marble.
Porphyry.	*Schist.*	*Flint.*
Felsite.	Mudstone.	Chert.
Granophyre.	Phyllite.	Pit Flint.
Keratophyre.	Schist.	Surface Flint.
Microgranite.	Shale.	
Porphyrite.	Slate.	
Porphyry.		
Rhyolite.		
Trachyte.		
Andesite.	*Quartzite.*	*Artificial.*
Andesite.	Quartzite.	Slag.
Dacite.		

It is almost needless to say that much that has been said in this chapter equally applies to roads of a more modern type than ordinary water-bound macadam roads, such as those bound with "tar," "bituminous," or "asphalt" compositions, which will be dealt with in a succeeding chapter.

[1] See note on previous page.

CHAPTER IV.

TAR TREATMENT OF ROAD SURFACES.

The Dust Nuisance.—It is difficult for some of us now to remember the terrible nuisance that was caused by dust in the early days of the introduction of self-propelled traffic on the water-bound macadam roads which then prevailed throughout the country. It was stated that this dust was not only a nuisance but dangerous to the public health; it was proved to be calcareous and argillaceous, and, as a well-known medical journal of that date stated, "once this dust secures a firm lodgment in the tissues of the lungs, the result of this effect, in the long run, will be the dreaded phthisis". It was also stated that there was the danger of "disease germs in the organic matter with horse and other animal traffic," and the evils attending the dust nuisance were largely dealt with by the Public Press. It was alleged that the bodies of most cars were nearer to the ground than horse-drawn vehicles, and that the body of air passing under a car, proceeding at high velocity, swept the dust into the air.

Action of Motors on Dust.—This theory was afterwards disproved by careful "dust trials" inaugurated by the Royal Automobile Club and others. What happens is that the driving wheels of a self-propelled vehicle brush the road, especially when running at high speed, and the tyres fling the dust to a considerable height. A motor car running at 20 miles an hour will produce a speed revolution of the tyres equal to about 30 ft. per second of the periphery; the centrifugal force on the small particles comprising the dust are naturally hurled to a considerable distance. It was found that watering a road could not cope with the altered conditions of traffic, and of course watering is impossible in many of our rural roads, so that to meet the difficulty a large number of "Dust Palliatives" were introduced by chemists and others.

Dust "Palliatives".—It might be well for purposes of record and history to enumerate the names of some of these palliatives. Though the list is probably very incomplete, they are as follows: Antistoff, Antistandlit, Akonia, Apokonin, Crempoid, Calcium Chloride, Dustabato, Duralit, Erminite, Epphygrit, Gonasto, Gulophin, Hahnite, Lyminite, Marbit, Pulvercide, Pulverite, Rapidite, Rustomit, Sprengelithe, Standertine, Tarvia, Tarco, Tarracolio, Westrumite.

The object of all these so-called palliatives was to bind the fine material together, comprising the dust, and to fix it on the surface of the road, but they, or most of them, had no permanent effect, and their application had to be repeated at frequent intervals. They were mostly composed of light oils or forms of tar, tar emulsions, salt, and other solutions. Of these, the light oils and tars, as well as other emulsions, are dependent for their effect upon the retention by the road surface of a small amount of binding after the volatile products have evaporated. This is only effective so long as the binding power is retained, and when this is lost, a further application is necessary, thus it is the base that forms the true binding material, and consequently the heavy oils and tars are the best in this respect. The salt solutions are only hygroscopic, and rely entirely on their affinity for water, thus keeping the surface of the road moist.

Tar Spraying.—But it is very true that "out of evil springs good," and the result of all these trials of various materials was that "tar painting" or "tar spraying" was introduced, and has now become a universal practice where a more expensive description of road surfacing, than that of ordinary water-bound macadam, cannot be substituted for various reasons.

In the early days of tar "painting" crude gas tar was used, spread, and brushed into the road surface by hand. In some cases this was fairly satisfactory, but in many cases it naturally failed; a black, sticky mud was produced, and there were many outcries against its use.

Suggestions by the Roads Improvement Association.—Early in the year 1914 the Roads Improvement Association issued a leaflet to the effect that they were continually receiving complaints from all classes of road users of the unsatisfactory results obtained from road tarring work, and that investigation of these reports indicated that in most instances the unsatisfactory results had occurred "in consequence of the non-observance of elementary principles in road tarring work". They therefore made suggestions for the guidance of those actually engaged upon road tarring operations, which may be considered as follows:—

(1) To obtain good results, it was absolutely necessary to be satisfied that the crust and foundation of the road were sufficiently strong to carry the traffic that might reasonably be expected. If not, it would be better to spend the money upon strengthening the road, and postpone the tarring work.

(2) The road surface should not be treated with tar until it had been thoroughly cleansed from dust, caked mud, and dung [special brooms to be used for the purpose], as otherwise the tar would not adhere properly to the road.[1]

(3) Before proceeding with the tarring, it would be advisable "to take out pot-holes, ruts, and similar irregularities in the surface, peck round them and remove the worn granite and other material to a depth of 1½ ins. to 2 ins. to secure an ample key and body to the patch; carefully brush the hole over with hot tar, and fill in with previously tarred 1½ ins. to ¼ in. graded material, using the greatest care to ram solid. The patch should be so finished that it is not more than ¼ in. higher than the adjacent surface of the road, to allow for shrinkage and further consolidation under traffic. If this course is carefully followed, the patch quickly becomes level with the surrounding surface," and that this work should be done during the winter, or early spring, preceding the tarring operations.

[1] In order to thoroughly prepare the surface of a road to take the tar properly, it is advisable to first brush the road with a horse-drawn or mechanically-propelled brush, then to sweep with hand brooms, and, finally, just before the tar is applied, to sweep the surface with hand hair brooms.

(4) "Under no circumstances whatever should an attempt be made to apply tar or similar compounds to road surfaces until the road is thoroughly dry to a point at least half an inch below the surface. The slightest damp means absolute failure. Often a surface appears to be sufficiently dry, but a careful examination should be made below the upper surface to make certain. Hot tar will not penetrate a damp road, nor will it adhere to damp road metal. Tar applied to a surface not thoroughly dry merely forms a skin which quickly denudes or detaches itself under the action of traffic, forming objectionable tarry dust or mud. Further, the road itself, being robbed of its natural means of surface evaporation, remains damp, and, therefore, rapidly decomposes under the waterproof skin, which soon breaks up, and ceases to keep out the water. It is quite impossible for roadmen to cope with the tarry mud that forms as if by magic soon after the first autumn rains, and continues throughout the winter consequent on tar being applied to a road that was even slightly damp. Not only is this tarry mud a source of inconvenience and annoyance to road users and roadside dwellers, but it also facilitates inter-attrition between the stones of the crust of the road, and thus increases the wear, so that, instead of a saving being effected from the use of tar, the ultimate cost of the maintenance of a road thus badly tarred is materially increased.

(5) "Great care should be exercised in the selection of the tar to be used. The various proprietary tar compounds are mostly well distilled and satisfactory, and are all guaranteed safe for use in proximity to fishing streams or ponds. Crude coal tar, however, requires special care as it contains ammoniacal liquor and other constituents that are not only useless to the road, but, being soluble in water, will pollute streams or ponds into which the road washings might discharge.

"Most gasworks are now equipped with a dehydrating plant, and are thus able to extract the dangerous ammoniacal liquor and some of the lighter oils, phenolic bodies, and naphthalene from the tar before they supply it to the consumer. A fair tar should weigh about 12 lbs. per gallon at about 60° F., and should contain no ammoniacal liquor. Many, if not all, of the defects of ordinary crude gasworks tar, so far as road work is concerned, may be removed if the tar is well heated.[1]

(6) "Great care should be taken to apply only that quantity of tar to the road which it will readily take, and at the same time amply cover the surface; this quantity usually lies between $\frac{1}{6}$ and $\frac{1}{4}$ of a gallon of tar per square yard of road surface. Any surplus tar which collects in puddles should be removed at once; if this is not done, the surface becomes troublesome at these points on hot sunny days, and much annoyance is caused to the public.

"Wherever local circumstances permit, the freshly applied tar should be allowed time to sink into the road surface, and slightly to harden before traffic is turned on, or any sand or grit is applied. This is best attained by treating one-half of the width at a time, and going back to the starting-point to commence the second half-width.

"The gritting should be one-half sharp sand and one-half larger grit, the grit not to exceed $\frac{3}{16}$ in. Sand and flint grit are the cheapest and most efficient gritting material. When granite chips are used, they should be very small, none larger than $\frac{1}{4}$ in.—the smaller is preferable. Where slag dust is available it is a valuable material to use, and it forms a durable skin.

"With sand or flint gritting no rolling is necessary. When granite chippings or other hard material is used, however, it helps to produce a durable skin, and to incorporate the material with the original road surface, if, a few hours after the chippings have been applied to the tarred surface, a roller is passed over it."

These suggestions were excellent, and cover most of the points in connection with this work, whether done by hand or by machine, but the following "instructions" to his staff, which were issued by Mr. R. J. Thomas, M.Inst.C.E., the County Surveyor of Buckinghamshire, are even more practical, and give fuller details of the manner in which this work should be executed:—

[1] This question of tar is dealt with in detail on page 115.

"**Instructions for Tar Painting.**—(1) *Road to be Dry.*—No tarring to be attempted unless the road is quite dry to a depth of at least 1 in., and the weather shows every appearance of being settled.

"(2) *Work to Cease if it Rains.*—All tarring to cease as soon as a fall of rain sufficient to soak the road takes place, and not to be resumed until road has quite dried.

"(3) *Complete Removal of Dust.*—The road to be swept hard with machine and hand brushes before tar is applied, the dust being picked up at once in slop or suitable carts, and removed, if possible; or, failing this, brushed into the gutters for early removal. In streets the dust must be removed as soon as swept up.

"In no event is dust to be left on metalled portions of roads where motor and other wheels can traverse and disperse it.

"(4) *Inspection of Tar, etc.*—Frequent inspection to be made of the tar barrels to ensure that they are full, and, where local gasworks supply, it is desirable to examine the pumping apparatus for filling barrels at tar-tank, and arrange that the suction-pipe is sunk well below surface level of tar, so that the diluted portion at top is not drawn upon. Care to be taken with barrels from foreign firms in their unloading and return. Defective barrels or material to be reported immediately.

"(5) *Screening Tar.*—All tar to be passed into boilers through a fine mesh wire screen to intercept all solids.

"(6) *Refilling Boilers.*—As soon as sufficient boiling tar has been run out for sweepers to go on with the boiler is to be gradually filled again; on no account is it to run empty and so have it stand until the freshly added tar boils.

"(7) *Application of Tar.*—The tar to be boiling when discharged through sprayer, and to be immediately brushed backwards, forwards, and across the area to be coated until it has been absorbed into the road fabric, and no puddles or blotches of any kind are left on the surface, which should be smooth, close, and free from blisters or bubbles; the outer edges in particular being brushed hard towards centre to prevent all running to the side gutters. Where entire width of a street is treated the gutters, unless made of close-jointed, non-absorbent materials, to be tarred, but very lightly, and every care taken to remove all puddles from between joints.

"It is necessary to have two or three damp sacks at hand, in case tar catches fire, in order to throw upon the boiler lid when same is put on.

"It cannot be too insistently pointed out that the principal object in tar painting is to secure as deep penetration of tar below the surface of the road as possible, in order to keep the metalling together under motor traffic, and that the thinner the coating on the surface the better.

"(8) *Whole-width Tarring.*—Where entire areas of roads or streets are to be tarred, it is done in two widths by coats about 100 yards in length with 20 to 30 yards intervals between, to provide room for traffic to pass, and to stand for business purposes; these spaces being tarred when the former are dry.

"The above coatings are to vary in width, the first being carried across street to within 9 ft. of other side, the second length being tarred only 9 ft. wide [leaving all but 9 ft. for traffic], the third, like the first, and so on. This will provide enough room for two lines of traffic to pass opposite alternate coatings of tar in a fairly wide street. Coatings to terminate in line with centre of side streets, private, or business entrance, etc., coming on to main road, so that traffic can pass to and fro, the space so left being tarred when earlier work is dry. Where it is unavoidably necessary for business or other purposes to traverse wet tar, it must be neatly covered with clean, sharp sand, to a sufficient depth to prevent licking up, and be frequently attended to and renewed if necessary.

"(9) *Tarring Centre of Roads, etc.*—Where roads are to be tarred to 10 ft. or other width along centre, it is to be done in two strips, the second being started where first commenced when that is quite dry.

"Roads much used by motors to be tarred full width round sharp bends and corners.

"(10) *Interference by Rain.*—Should heavy rain come during operations and look like scouring the tar from centre to sides of road, prompt steps must be taken by placing sufficient clean, sharp sand [not road scrapings or fine gravel] along outer edges of tarred area to prevent tar being washed away. If, in spite of this, the diluted tar finds its way to the untarred portions of road at sides, it is to be at once brushed hard into the roadside gutters and kept there.

"(11) *Barriers, Lighting, etc.*—Every precaution to be taken to warn traffic by red flags, effective barriers, etc., during the day, and ample lamps with watchmen in attendance throughout each night; and when the second portion of a central strip is being laid, barriers, barrows, or other obstacles must be placed upon it at each end, and at intervals, during daylight, to indicate clearly that the other half is the dry one. At night the whole undried work to be effectively lighted, as already described.

"(12) *No Tarring on Saturdays.*—All tarring to cease on Friday evenings, so that by Saturday night all will probably be dry enough to justify removal of barriers, lights, etc., for Sunday. Boilers to be used on Saturdays for mixing tarred granite, chippings, etc., for repairs.

"(13) *Cleaning Boilers, etc.*—Screw heads to ends of sprayer to be removed whenever necessary, and the pipe well scraped through and cleaned by means of an iron rod fitted with a worm-thread or a wire rose-head.

"(14) *Generally.*—Every care must be taken to reduce obstruction to traffic and local inconvenience to a minimum. Instructions as to widths and lengths to be tarred, etc., must be strictly followed."

In a communication to "Practical Road Engineering," published by St. Bride's Press, Ltd., Mr. Thomas gave some further very useful information with regard to road tarring. For instance, he says, *inter alia*, that, as a rule, he tarred only a width of about 12 ft. of the surface of a road, as he found this was sufficient for the majority of the traffic. This appeared to take about 1,090 gallons of tar per mile of road. He says he does not sand or dust with stone chippings on completion of the tarring, as he considers that a more lasting and solid surface is produced without this addition. His view appears to be that in dry weather sufficient dust adheres to the tarred surface to make it quite sufficiently non-slippery. He found that "on an ordinary granite road penetration is secured of from 1 in. to 2 ins.; on flint and gravel an inch more," and that roads "tarred two years in succession require from 20 to 25 per cent. less tar for the second application". He also gives details of the cost of this work, but these costs are now, of course, quite valueless, owing to the great increase in the cost of labour, haulage, and price of materials since the War.

Road Board Directions.—The Road Board also issued some "General Directions for Surface Tarring" which begin with a general statement that surface tarring may be advantageously applied either to an old road surface in good condition or to a new surface after consolidation, but that the tarring should never be carried out unless the road surface is thoroughly dry and all pot-holes, depressions, waves, grooves, etc., made good before the tarring is commenced, and as to whether the work should be done by machine or hand must depend on local circumstances. Similar advice to that already mentioned is given with regard to the early preparation of the road surface and the necessity for keeping it free from mud before the tar is applied. If the road is thin at the sides, but adequate in the centre, the sides should be strengthened and consolidated before the surface is tarred, and in carrying out any work of re-surfacing, "stone chippings, and not fine material should be used for binding".

This is important as it has been found that where any earthy material has been used for binding, the tar will neither penetrate or adhere.

With regard to the cleansing of the surface the Board suggested that "any method of brushing may be used which will scour and clean the road thoroughly, the best being horse brushing followed by hand brushing".

With regard to the quality of the tar which should be used they recommended that it should either comply with their specifications for tar No. 1 or No. 2, but that if the latter is used "care should be taken to apply it only when the road is well warmed by the sun's rays, otherwise it will not flow freely". If tar No. 1 is used the best temperature to which it should be raised lies between 220° and 240° Fahrenheit, and for tar No. 2 between 260° and 280°, and detail suggestions are given as to the cans to be used if hand spreading is to be employed, and the importance of regularity of the thickness of the coat.

With regard to the gritting or dusting of the surface they recommend that "if the road must be opened for traffic before the tar has set hard, grit should be spread on the surface to prevent the tar from adhering to the wheels of vehicles, but gritting should be delayed as long as possible, and the quantity of gritting material to be spread should be no more than sufficient to prevent the tar from adhering to wheels. Stone chippings, crushed gravel, coarse sand, or other approved material [free from dust], not larger than will pass through a ¼-in. square mesh should be used for gritting."

Tar and Fish Poisoning.—In the early days of tar painting roads there were numerous complaints that the tar found its way into streams and rivers thus poisoning fish, and in these recommendations by the Board they state, "precautions should be taken to prevent liquid tar passing directly through drainage gratings or outlets".

On this question of danger to fish life Mr. W. J. A. Butterfield, M.A., etc., read a paper before the Institution of Municipal and County Engineers on February 9, 1912, in which he dealt at length with the whole question, and stated, *inter alia*, that "probably the most serious risks of pollution of water occur during a drizzle or long-continued rainfall which at no time is heavy, as in that case the water will remain for a comparatively long period in contact with the tarred surface before draining from it into water-courses". This applies to tarred roads long after the work has been done, and if it does occur the remedy appears to be difficult, but during recent years, the outcry that was at one time raised of fish poisoning from tarred roads seems to have died out, probably arising from the use of purer tars than were formerly used, and consequently this objection to the practice of road surface tarring may be dismissed.

This is borne out by Mr. Butterfield's concluding remarks which are as follows:—

"The Surveyor may safeguard himself in the use of tar on roads in all ordinary cases if he uses only coal tar or a mixture of coal tar and carburetted water gas tar, which in either case (1) is of not lower specific gravity at 15° C. than 1·18; (2) contains not more than 1 per cent. of water or gas liquor, the ammonia in which is equal to not more than 5 grains per gallon of tar; (3) contains not more than 1 per cent. of light oils; and (4) contains not more than 3 per cent. by volume of crude tar acids.

"If cases occur where the washings from tarred roads will not be diluted to at least twenty times their volume before, or immediately on, entry to fishing waters, the maximum limit of water or liquor in the tar should be reduced to 0·2 per cent.; of ammonia to 1 grain per gallon of tar; and of light oils to 0·8 per cent. [or 1 per cent. of distillate below 170° C. inclusive of water]. As an extreme precaution in certain cases, a tar prepared from pitch and 'dead' tar oils [i.e. middle and heavy tar oils from which the phenols have been extracted] might be used, and when the market value of carbolic acid, etc., is high, the cost of such a prepared tar should not be very much greater than that of an ordinary good 'freed' coal tar."

This question was referred to again by Mr. Butterfield quite recently in "The Fishing Gazette" of April, 1919, where he pointed out that a tarred road is likely to be dangerous to fish life where the river runs in a valley and the roads incline for long distances towards a bridge spanning the river. In such a case a very large area of road surface might drain into the river. He points out that this would be the worst possible case that could happen, but that it is a remote contingency, and further he states that it is only in very few instances that a roadway drains directly into a river, while the road washings are considerably reduced in potency by passage overland, through soil, or through filtering or ærating beds. The figure adopted for the above argument, this figure being the maximum degree of pollution obtainable, is far greater than that which can be obtained by the washings from a properly tarred surface which is neither quite new nor worn. For example, a vessel was filled with water after having been painted with tar five days previously, and by means of a jet, the contents of the vessel were changed once in every thirty-five minutes. It was found that various fish, including two trout, existed safely in the vessel for six days without any apparent ill-effects, after which period they were returned to a stock tank. He further remarks that a tarred road is likely to be most dangerous to fish life (1) when a heavy rainfall occurs immediately after tarring the road whereby some of the tar is lifted before it is set or hardened, and (2) when the rain can premeate freely through the coating of tar which has become broken up through age and wear and tear. This condition is found to some extent in the dust which is found on tarred roads after prolonged drought, but to a far greater extent when a tarred surface or a tarred macadam road has been scarified.

On the whole, therefore, it may fairly be assumed that with reasonable precautions the danger to fish life by the surface tarring of roads is very remote, if not altogether negligible.

Turning again to the Board's recommendations they then dealt with the question of the public safety, whilst the work of tarring is in progress, and say that "precautions should be taken by lighting, watching, and warning, and they recommend that Notice Boards should be placed in suitable positions bearing in large letters printed in conspicuous colours the following:—

CAUTION
TARRING IN PROGRESS
CYCLISTS ADVISED TO WALK.

The Board further recommended that on roads of heavy traffic it was advisable to apply a second coat to either the whole width or from 9 to 12 ft. of the centre of the road, in quantity of 1 gallon for 8 to 10 square yards, and this should be done about two or three months after the first application.

They recommended, also, that surface tarring should be renewed annually, in such quantity as would appear to be necessary to replace the tar removed by traffic or weather.

Finally, surveyors are recommended to have samples of the tar supplied to them under contracts properly tested by a qualified analytical chemist for specific gravity, freedom from water, fractionation, and free carbon.

This last recommendation raises the all-important question of the proper tar or proprietary article which should be used for road surfacing tarring, but before dealing with this subject, it might be well to refer to some of the various suggestions and recommendations which have been given in detail with regard to this description of work.

Grit Sprinkling.—For instance, there appears to be some difference of opinion with regard to the question of sprinkling [with sand, gravel, or chippings] the surface of a newly tarred road. Some surveyors contend that such a practice, especially if gravel or chippings are used, tends to cut up the surface as the gravel or chippings are forced through the skin of tar, thus letting in the water and helping to disintegrate the road. The object of this sprinkling is (1) to absorb some of the tar and thus facilitate drying; (2) to form a thicker skin and protection than is afforded by the tar alone; (3) to prevent the surface becoming slippery. There are certainly arguments on both sides, but I am not aware of any authentic results of either practice having been published, so the question must remain in abeyance.

The materials generally used for this "spreading" are either sharp, clean sand, fine sifted slag dust, granite or other chippings, about ¼-in. gauge, shingle or ballast from ⅛-in. to ¼-in. gauge, cinders or clinker dust, or other sharp, clean material, but, of course, the choice of material must be guided by local considerations. The method of spreading the material also differs; in some cases it is done with a shovel by hand, requiring some skill, in others by machines which scatter the material automatically as the machine travels. It is advisable that whatever process is adopted the wheels of the machine should not travel on the newly tarred surface, but on the part of the

Grit Sprinkling Hand Machine.

road on which the material has already been spread. This seems to be accomplished in the machine given in the illustration. [See Plate VII.]

Methods of Tar Spraying.—Another point in connection with the surface tar spraying of roads has been the question as to whether the tar can be more effectively spread by hand or by machine. Some surveyors contend that, as tar is a very viscous fluid, it is better and more effective to pour it hot on to the surface of the road and then brush or squeegee it to an even surface, and that this work can be more effectively performed by intelligent hand labour than by a machine. Other surveyors contend that, as this description of work should only be carried out during dry weather, of which we do not have too much in this country, it is essential that the work should be done as expeditiously as possible, and that this is effected more quickly by a travelling machine than can be done by hand.

It is also contended that, if the machine is of the "pressure" type and not the gravity type, the force with which the atomised tar is projected out of the nozzles of the spreader drives the tar into the surface of the road, thus ensuring a greater penetration. It is also contended that such a machine gives a better uniformity of spread, and, as it would thus be more "even," economy in the quantity of tar used is secured. A further point in favour of "pressure" machines is sometimes raised, that the hot tar is atomised, and that the blast of hot air accompanying it tends to warm and dry the surface and drive off the finer particles of dust which may still remain on the surface, notwithstanding the brushing and brooming it may have received, thus allowing every particle of the tar to penetrate into, and adhere to, the surface of the road. The advocates of hand application do not agree with this, and say that the air in the small voids in the road surface prevents the tar from penetrating, and that it is better to give the road as much tar as it can absorb, and a liberal allowance of sand or fine gravel spread on the surface takes up the rest of the tar.

It is claimed for a machine with an air pressure of about 180 lbs. on the square inch, and the tar maintained at a temperature of 250° F., that it is able to cover about 12,000 square yards of road surface during an ordinary working day, with an expenditure of tar of between 4 and 5 gallons per square yard of surface so treated.

It is, on the other hand, claimed by the inventor of a well-known "hand" system of tar painting by means of special distributing cans and reversible squeegees, that 1,000 square yards of road surface can be covered in a hour by three men with tar at the proper temperature, and that perfect evenness of spread is secured.

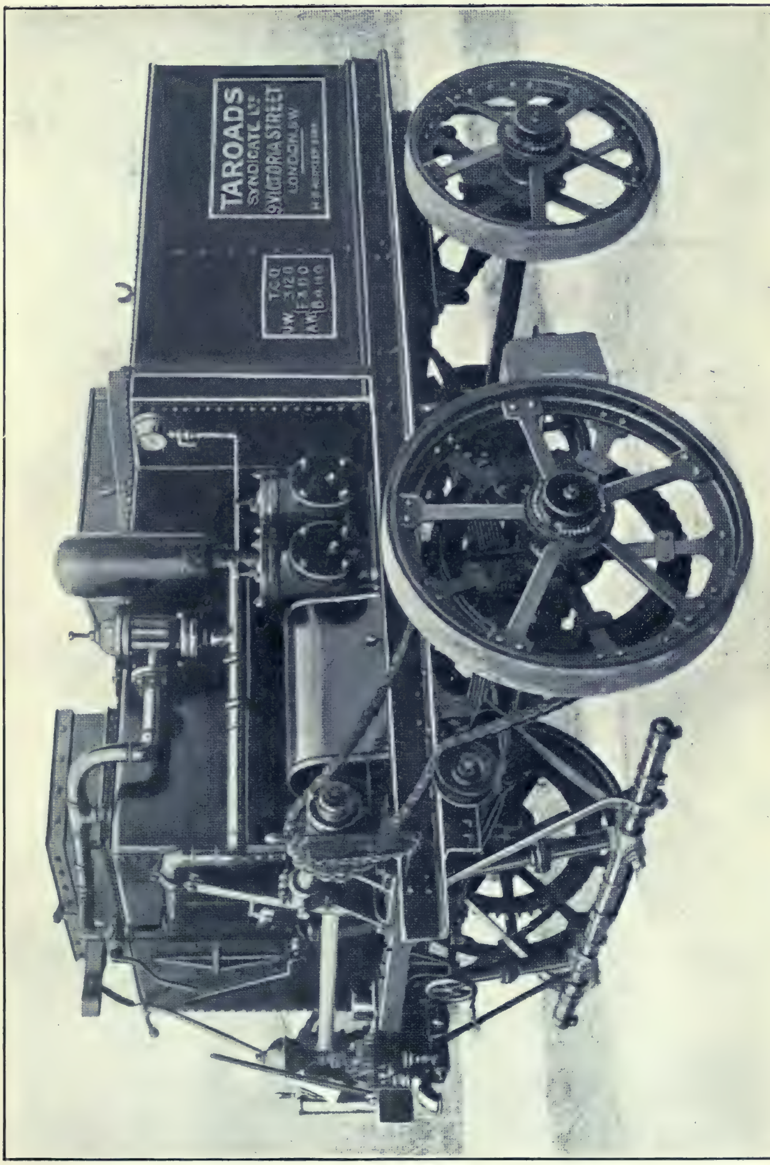
With regard to the difference of opinion which appears to exist as to the various merits of pressure machines *versus* gravity machines, the following particulars will be of interest:—

Pressure Spraying Machines.—Mr. Henry E. Stilgoe, M.Inst.C.E., the late City Engineer of Birmingham, and now the Chief Engineer of the Metropolitan Water Board, used ten tar spraying pressure machines, each of 1,000 gallons capacity, of the type shown on Plate VIII.

These machines are not self-propelled, but are hauled either by a steam road roller or a steam tractor. Mr. Stilgoe does not consider there is any advantage to be gained by being self-propelled, as these machines are only used during a small portion of the year as weather permits. He used tar distilled in accordance with the Road Board's specification, particulars of which have already been referred to in this chapter.

Mr. Stilgoe preferred the use of pressure machines to gravity machines or hand painting for the reason that, in busy city streets, it is necessary to execute the work as rapidly as possible, for, as he justly remarks, "the quicker the work is performed the better it is for the convenience of the public, and the cost is reduced accordingly".

He was further of opinion that the machines which spray the tar under pressure give a more even distribution, and that the tar penetrates between the stones. At the same time, he was "not prepared to say that as good results might not be obtained by the slow and laborious process of rubbing the tar



Type of "Pressure" Tar Spraying Machine.

Type of "Gravity" Tar Spreading Van.

Improved Type of "Gravity" Tar Spreading Machine.

into the road with a hand brush, but that it is certainly more costly and much slower".

From a report given by Mr. Stilgoe to the Council it appears that, during the tar-spraying season of 1917, no less than 1,106 roads were thus treated for the first time, with a total area of 4,043,158 square yards, and 60,596 square yards of road surface were tar sprayed a second time. The whole of this work was done in 70 days, so that, adding the area of surface tar sprayed a second time, this would make a total area, tar sprayed in 70 days, of 4,103,754 square yards, and, assuming that all the ten machines were engaged the whole of the time, which is somewhat unlikely, this gives a total area, sprayed by one machine in a day, equal to about 7,000 square yards a day.

Having thus dealt with the experience and opinions of a well-qualified expert on the subject of tar treatment of roads by means of pressure machines, the author will now turn to the experience and opinions of an equally well-qualified expert on the advantages of using only gravity machines supplemented by hand labour.

Gravity Spreading Machines.—At Norwich the procedure for some time past has been to apply the tar to the surface of the road at a temperature of from 180° F. to 200° F. from an old water van fitted with two outlets at the rear, behind which are trailed a weighted broom extending the full width of the van. Any places missed by this broom are brushed into place by a man following the van. [See Plate IX.]

This was quite successful, but Mr. Arthur Collins, M.Inst.C.E., the City Engineer, considered that it was not sufficiently rapid in its work, and, whilst continuing this practice, has recently improved on this system by having had constructed two well-lagged cylindrical bodied vans, each of 300 gallons capacity, with tar spreaders made of perforated gas-pipes controlled by taps.. [See Plate IX.]

These vans are filled at the gasworks with tar at a temperature of 360° F. to 400 F., and it keeps its temperatu re for quite 12 hours after the vans are filled, owing to the clothing or lagging of the vans.

Weighted trailing brooms, somewhat longer than the spreaders, are attached behind the vans, as in the case of the adapted water van.

Mr. Collins states that he uses pressure machines and gravity machines, and that, as regards penetration and all-round efficiency, he sees no difference. More care has to be taken with any machine in which the tar has to pass through pipes or small holes than otherwise. He likes the tar pipes, and fittings, emptied, so far as practicable, at the close of each use. He specially designed the tubular tar spreader of the cylindrical hot tar van, with taps or plugs, at all important points, with a view to this, so that clearing rods can be readily passed through the necessary pipes, etc. The difficulty sometimes experienced by "blocking" has been eliminated by the use of large discharge pipes, controlled by cocks. He uses a very much thicker tar than is generally used, but he objects strongly to the use of tar thickened by adding pitch. He uses tar in which distillation is stopped immediately anthracine is reached, and he uses it as hot as possible.[1] The cylindrical tar vans are fitted with steam coils, to which a steam hose can be connected, and steam turned on so as to heat the tar again if it has had to remain unused [on account of unfavourable weather or other causes] for some time in the yard. He lays a "liberal coating" of this very hot thick tar on the road, and covers it with $\frac{3}{8}$ in. to $\frac{1}{2}$ in. local gravel, and then rolls it with a steam roller; on tar-paved footpaths he uses a thinner tar, and smaller grit, the size of peas or less, and hand rolls it.

The above remarks and conclusions of a man of Mr. Collins' wide experience and judgment are very useful in this direction,

[1] Mr. Collins says that experience has brought him to the conclusion that where a thin tar is thickened by adding pitch, a mixture likely to be brittle in use results, as there is not enough anthracene in this tar to give the necessary toughness to the pitch. It is all a question of degree, and depends on the actual tar and pitch used; to be on the safe side, he prefers to use tar in which the distillation is stopped immediately anthracene is reached, as then the volatile portions have practically gone, and the harder, including the toughening, elements are retained.

viz. whether pressure machines or the application of tar by gravity are preferable, but each case must be taken on its merits, and where the exigencies of traffic require a quick application, no doubt a pressure machine is able to do the work more quickly.

Before passing from the question of the tar treatment of road surfaces, it is rather interesting to note that the American road engineers call this work "carpeting," whereas our nomenclature calls it tar painting or tar spraying, and what we call a "carpet" the Americans call "sheet asphalt pavement".

For instance, under the "terminology" adopted by the American Society of Civil Engineers, the following definitions are given:—

"*Carpets* are bituminous surfaces of appreciable thickness, generally formed on the top of a road or pavement by the application of one or more coats of bituminous material with gravel, sand, or stone chips added.

"*Sheet Asphalt Pavements* are those having a wearing surface composed of sand of predetermined grading, fine material, and asphalt cement, incorporated together by mixing methods."

Tar Suitable for Spraying or Painting.—It is now necessary to turn to the very important question as to the best description of tar to use for the purpose of tar spraying, and authorities on the subject are, I believe, agreed that coal tar, produced from the destructive distillation of coal, is the best for the purpose.

In the Road Board's specification of tar suitable for the surface tarring of roads, it is stated: "The tar shall be derived wholly from the carbonisation of bituminous coal, except that it may contain not more than 10 per cent. of its volume of the tar [or distillates or pitch therefrom] produced in the manufacture of carburetted water gas".

And with regard to tar from gasworks, they say: "The tar shall be solely the natural by-product of the manufacture of illuminating gas [coal gas with or without admixture of carburetted water gas], and shall have been subjected to no other or further treatment than may be necessary for the abstraction of water or ammoniacal liquor and light oils".

With reference to tar from tar distilleries, after specifying certain qualities it must possess, they say: "A tar prepared by simple dehydration fulfilling the provisions of this specification may be used with satisfactory results in most cases, but tars from which the naphthalene has been extracted are superior for the purposes of surface tarring".

This last clause, of course, applies to the whole specification for the three descriptions of tars mentioned, and reference has been made to clauses quoted simply for the purpose of showing that the Road Board were of opinion that coal-gas tars were the proper tars to use for the purpose. Oil-gas tar and water-gas tar appear to be unsuitable for the purpose. With regard to coke-oven tar, this does not appear to differ very materially from ordinary tar from gasworks, as the following table of their percentages of certain compounds will show:—

	Gasworks Tar.	Coke-oven Tar.
Pitch	58·4 per cent.	44·2 per cent.
Anthracene	17·5 ,, ,,	27·5 ,, ,,
Water	2·9 ,, ,,	2·2 ,, ,,
Creosote oils . . .	8·6 ,, ,,	14·5 ,, ,,
Free carbon . , .	15 to 25 ,, ,,	5 to 8 ,, ,,

So it would appear that, in some respects, coke-oven tar is even more suitable than gasworks tar, as the latter is usually distilled at a higher temperature than coke-oven tar, and consequently is likely to contain more free carbon, and less of the heavy oils.

In the earlier days of the use of tar, etc., for roads, the following was considered quite sufficient guide to surveyors as to the quality of tar: (1) The tar should be coal-gas tar, and not contain more than 10 per cent. of tar obtained from carburetted water gas. (2) It should be perfectly free from water and ammoniacal liquor. (3) Its specific gravity should be not less than 1·18 or more than 1·24. (4) It should be devoid as much as possible of phenol or phenol compounds. (5) It should not contain more than 18 per cent. of free carbon. (6) When heated to 170° C., the distillation should not exceed 1 per cent. (7) Pitch should be coal-tar pitch, and contain not more than 10 per cent. of pitch produced in the manufacture of carburetted water gas. (8) It should not become soft at any temperature below 68° C. (9) When heated to 270° C., it should not yield more distillates than 1 per cent. (10) It should not contain more than 18 per cent. of free carbon. (11) The specific gravity of the heavy oil should be between 1·065 and 1·075. (12) The oil should be free from naphthalene. (13) The oil should have a flash-point of 75° to 80° C. (14) The boiling-point of the oil should not be below 300° C.

These were the "14 points" settled by various experts, but, since then, the Road Board's specifications for tar and pitch of an elaborate character have been issued, and have been adopted by the British Engineering Standards Association.

It would be useless to give these specifications, as they can easily be procured from Messrs. Waterlow & Sons, Ltd., the well-known publishers, etc., of London Wall, London, E.C. 2, or from the Secretary of the British Engineering Standards Association, 28 Victoria Street, London, S.W. 1.

There can be no doubt that the question of using the proper tar, or proprietary refined products, is of paramount importance, and, unless a surveyor is perfectly sure that he is getting the right description of material, he should send it to be analysed, on the lines of the Road Board's specification, to an analytical chemist who has made a speciality of this class of work.

For many years to come the practice of tar spraying, or tar painting, the surface of roads will have to be continued, and it is essential that proper materials and proper methods should be employed. There are not many surveyors who are fortunate enough to have a laboratory, or even the instruments for making the necessary tests, but facilities are offered at the Physical Laboratory at Teddington and elsewhere for having the necessary tests made, and the days of haphazard work should be relegated to the "limbo of the past," or, more shortly, as an engineer would put it, "scrapped".

Statistics.—It would serve no useful purpose to give any details of the cost of tar painting or tar spraying, although the author has a large number of detail figures at his disposal. The cost of labour, haulage, materials, and everything connected with this description of work, have so completely altered since the outbreak of the Great War, that they are now almost valueless:—

The following table, however, of the hours employed by the workmen, and other details, may be useful as a guide to surveyors and others engaged on this class of work; the costs can be easily calculated from local prices, and the total cost per square yard ascertained. The work was executed by hand on a rural road:—

	Hours.
Horse-machine sweeping and cartage in removal of sweepings	·0034
Labour, assisting in above	·0034
Labour, heating and applying tar, and afterwards spreading chippings	·0450
Carting chippings to site	·0040
Tar used per square yard	·350 gallon.
Chippings for "dusting"	·0054 ton.

If some such statistics as these are kept on a job of this description, very useful local information could be obtained, which would be of service to the surveyor in estimating the cost of any similar work in his district.

CHAPTER V.

BITUMINOUS ROADS.

THE title of this chapter may be criticised as not being strictly correct, as of recent years the definitions of bitumens and asphaltes [now spelt without the final "e"] have been somewhat changed, and this will be referred to later.[1]

Early Attempts.—The question as to the exact date on which the first attempt was made to construct a bituminous road is not known, though there are several claimants for the honour.

The early attempts were very simple. Ordinary road metal, broken to any suitable size, was heated and dried by being spread, in a thin layer, on cast-iron plates supported on low sleeper walls; a fire was lighted and maintained under these plates, and the metal was turned over with forks until it was dry and slightly warm. Then ordinary crude tar, obtained from the tar well at the nearest gasworks, was heated and poured over the broken stone, which was well raked and turned over until each stone was more or less coated with tar. The treated material was then carted to the road and laid and rolled in the same manner as if it had been water-bound macadam, except that, of course, no water was necessary.

But the advent of self-propelled traffic brought about a complete change in the methods and materials employed in the construction of bituminous roads, and one of the first steps taken was to arrive at some conclusions as to the best sizes

[1] At the International Road Congress, held in Paris in 1913, this difficulty was, in some measure, met by calling the Section dealing with this subject, "Construction of Macadamised Roads Bound with Tarry, Bituminous, or Asphaltic Materials".

and descriptions of the metal to be used in the construction of roads.

Inquiries as to the Best Stone to be Used.—The British Standardisation Committee took up the question, and appointed a joint sub-committee of experts and representatives of stone merchants and quarry owners to inquire into the matter, and, if possible, to try and standardise road stone. The results of their investigations have already been given in the chapter on "Water-bound Macadamised Roads" [see p. 93]. Then the question of the best description of tar or other bituminous compound was taken up by road engineers and analytical chemists, not only in this country but in America and on the Continent.

Nomenclature.—One of the first difficulties encountered was that of nomenclature, and some controversy arose as to what was "Bitumen" and what was "Asphalt".[1]

[1] In a paper read before the Faraday Society on December 8, 1903, by Professor D. A. Sutherland, F.I.C., F.C.S., on "Bitumen in Insulating Compositions," he says, *inter alia*:—

"In Europe the term asphalt is usually, and as I think properly, restricted to limestones impregnated with bitumen. In America this is known as asphalt rock, or asphaltite, which terms are also applied there to bituminous sandstone.

"It has long been my habit to classify bitumen in grades as follows:—

Bitumen (proper): Trinidad pitch (or asphalt), Jew's pitch.
Soft bitumen: Maltha, mineral tar, kir.
Hard bitumen: Asphaltum, Manjak.

"But these terms are by others frequently used indiscriminately. Watts's dictionary speaks of asphalt as a 'compact bitumen,' but refers to the lake of 'bitumen' in Trinidad. Morley and Muir in their dictionary speak of asphalt as 'a natural product of the decomposition of vegetable substances,' and refer to it as occurring 'in a molten state in Trinidad, and as a mineral deposit in Seyssel. . . .'

"*The* natural bitumen *which is known as asphalt* is composed, as far as we have been able to learn, of saturated and unsaturated dicyclic, polycyclic, or alicyclic hydrocarbons and their sulphur derivatives, with a small amount of nitrogenous constituents. *Asphalt may therefore be defined as any hard* bitumen [is a natural substance], composed of such hydrocarbons and their derivatives, which melts, on the application of heat, to a viscous liquid; *while a maltha or soft asphalt may be defined as a* soft bitumen consisting of alicyclic hydrocarbons which, by heating or by other natural causes, becomes converted into *asphalt* [hard bitumen]. The line between the two classes cannot be sharply drawn.

"One meaning is agreed upon by all, that bitumen is a natural product, as

Some of the older road engineers in this country contended that "Bitumen" had always been understood to be a natural product, such as "Trinidad Lake Bitumen," and not the residue obtained by distillation of petroleum or other artificially produced material, and that "Asphalt" was understood to mean the natural rock asphalt found in various districts of France, Switzerland, and elsewhere.

Report of British Engineering Standards Committee.—Finally, the British Engineering Standards Committee took up the matter in 1913, and appointed a Sectional Committee to deal with the subject. In the preface to a report issued by this Sectional Committee in 1918, it is stated:—

"The drawing up of definitions for the so-called 'bituminous materials' used in road making, on which much confusion now exists, has been felt to be an essential preliminary to the preparation of standard specifications, and the Committee have devoted considerable time and care to the consideration of the exact meanings to be given to the terms Tar, Pitch, Bitumen, Native Bitumen, Asphalt, and Native or Rock Asphalt.

"It is hoped that the definitions now recommended will go far to prevent the misunderstandings which at present occur in specifying materials belonging to the bitumen and asphaltic group."

In their report the Committee again drew attention to the loose manner in which the term "bituminous material" has been applied to tar products as well as to bitumens and asphalts, and the necessity for making a "sharp line of demarcation between the two groups," and they proceeded to define the groups as follows:—

opposed to bituminous products obtained as the result of destructive distillation or by other artificial means. It is in this sense that I use it.

"The characteristics of native bitumen are not shared by artificial products such as gas tar; this has been amply proved by practical experience in paving, as also in the manufacture of insulating materials, where, all things being equal, the natural product, even at a higher price, is preferred to the artificial."

FIRST GROUP.—TAR PRODUCTS [PRINCIPALLY COAL TAR AND PITCH].

(1) *Definition of Tar.*—Tar is the matter [freed from water] condensed from the volatile products of the destructive distillation of hydrocarbon matter, whether this be contained in coal, wood, peat, oil, etc.

(2) *Prefix denoting Source of Origin or Method of Production.*—A prefix such as "Coal," "Wood," "Peat," "Gasworks," "Blast Furnace," "Coke Oven," etc., must be added to the word "Tar" to indicate the source of origin or method of production.

(3) *Definition of Pitch.*—Pitch is the solid or semi-solid residue from the partial evaporation of tar.

SECOND GROUP.—BITUMENS AND ASPHALTS.

(4) *Definition of Bitumen.*—Bitumen is a generic term for a group of hydrocarbon products soluble in carbon disulphide, which either occur in nature or are obtained by the evaporation of asphaltic oils. The term shall not include residues from paraffin oils or coal tar products.

NOTE.—Commercial materials may be described as *bitumen* if they contain not less than 98 per cent. of pure bitumen as defined above.

(5) *Definition of Native Bitumen.* — Native bitumen is bitumen found in nature, carrying in suspension a variable proportion of mineral matter.

The term "Native Bitumen" shall not be applied to the residuals from the distillation of asphaltic oils.

(6) *Definition of Asphalt.*—Asphalt is a road material consisting of a mixture of bitumen and finely graded mineral matter. The mineral matter may range from an impalpable powder up to material of such a size as will pass through a sieve having square holes of ¼-in. side.

(7) *Definition of Native or Rock Asphalt.*—Native or rock asphalt is a rock which has been impregnated by nature with bitumen.

(8) *Prefixes denoting Source of Origin.*—The Committee

recommend that, for convenience of identification, prefixes denoting geographically the source of origin should be attached to each of the four terms defined above.

American Definitions.—It will be of interest to compare the above British definitions with those of the American definitions which so far as can be ascertained may be assumed to be as follows:—

Bitumen.—A mixture of native or pyrogenous hydrocarbons and their non-metallic derivatives. It may be a gas, liquid, or solid; and if solid is soluble in carbon disulphide.

Bituminous Material.—Any material containing bitumen, or constituting a source of bitumen. Bituminous coal, peat, etc., are called pyro-bitumens because a bitumen may be produced from them by distillation. The ordinary bituminous materials used in roads and pavements are asphalt, petroleum, and tar.

Cut-back Product.—A petroleum or tar residuum which has been fluxed with distillate.

Asphalt.—Solid or semi-solid native bitumen, or solid or semi-solid bitumen, obtained by refining petroleum, which consists of a mixture of hydrocarbons and which melts upon the application of heat. Asphalt is usually found associated with various mineral and organic substances. Different varieties of asphalt are called albertite, grahamite, gilsonite, turrellite, wintatite, wurtzetite, etc.

Crude Asphalt.—A native mixture of bitumen, sand, clay, water, organic matter, etc.

Refined Asphalt.—A native mixture after it has been freed wholly, or in part, from water and organic and inorganic matter by being heated.

Rock Asphalt.—A limestone or sandstone naturally impregnated with asphalt. Rock asphalt is the principal form of asphalt used in Europe for paving purposes and is there usually designated as asphalt.

Desirability of Fixed Definitions.—The author may be somewhat prejudiced, but the British definitions appear to him to be more concise and more lucid than the American definitions, and it is to be regretted that some agreement could not have been come to in order that a sort of International Standard of Definitions might have been issued, instead of the present uncertainty which exists as to what is "Asphalt" and what is "Bitumen".

It was evident that the roads could not wait whilst these academic questions were under discussion and the road engineers were busily employed in constructing various types of bituminous roads all over the country, and their efforts were greatly helped by the sympathy and assistance of the then newly constituted Road Board. It would be impossible to give any history of the trials that were made, or of the various methods of construction employed in any chronological order. The various types of construction, however, will be dealt with, commencing with what is know as Pitch Grouting.

Pitch Grouting.—Mr. John A. Brodie, M.Inst.C.E., the City Engineer of Liverpool, was the pioneer of this method of road construction some eighteen years ago, when he commenced making roads in this manner. He has been good enough to furnish the author with the following particulars of the present manner in which he carries out this work :—

"*Upon a 10-in. foundation* of hand-pitched rock or of destructor clinker, laid and consolidated in accordance with the fourth class specification [for water-bound macadam], a layer of macadam stones of 2½-in. gauge, similar in quality to that used for water-bound macadam, shall be spread evenly to a depth of about 3½ ins. [before consolidation].

"This layer after being dry rolled with a light steam roller shall be grouted with a hot mixture of pitch and creosote oil, prepared in accordance with the specification below, and again rolled while hot until the mass is thoroughly consolidated.

"*A second layer* of similar macadam stones of 1½-in. gauge 2 ins. deep, shall then be laid, preferably while the lower layer is still hot. After being rolled dry, it shall be grouted in a similar manner with the pitch mixture; the surface shall be covered with a sprinkling of dry granite chippings, and the whole shall be again rolled until consolidated. The road shall be laid to an approximately circular camber, with a cross-fall from crown to channel of 1 in 48.

"**Macadam.**—*The macadam* shall be durable granite or trap rock from the quarries of North Wales, or from other approved quarries having a similar class of rock. It shall be carefully broken into cubical form so as to be capable of passing through the specified gauge in any direction. It shall be cleanly riddled to free it from dust, and all flat, slatey fragments shall be picked out before shipment. '2½-in. macadam' shall pass through a 2½-in. ring and be held by a 2-in. ring. '1½-in. macadam' shall pass through a 1½-in. ring and be held by a 1-in. ring.

"**Special Coal-tar Pitch.**—(1) *The pitch* shall yield no matter volatile below 270° C. when subject to dry distillation, and its total volatile organic matter shall not fall below 30 per cent.

"(2) *It shall not* contain more than 80 per cent. of its weight of matter insoluble in petroleum spirit of 0·700 specific gravity [boiling], and must be free from extraneous matter, such as sand and grit.

"(3) *It must twist fairly* after immersion for two minutes in water at 60° C., but not under 55° C.

"**Special Creosote Oil.**—(1) *The oil* supplied shall be obtained exclusively by the distillation of coal tar, and shall not contain any portion of distillate obtained below 240° C. None of it shall re-distil below 240° C.

"(2) *The oil* as obtained by distillation of coal tar shall not be treated in any way, either by the addition of any coal tar product, or by the extraction of any of its constituents, excepting such extraction as may be necessary to comply with Clause 3. It shall contain no moisture.

"(3) *It shall contain* no solid matter at 15° C. and shall have a specific gravity of not less than 1·075 [taking water as 1·00 at 15° C.].

"(4) *It shall contain* not less than 40 per cent. of its constituents that do not distil over below 320° C. and the 60 per cent. which does distil over below 320° C. shall contain 10 per cent. of tar acids, to be extracted by soda of specific gravity 1·125 [water 1·00].

"**The Pitch Mixture.**—*The pitch mixture* used for grouting shall consist of coal-tar pitch and creosote oil in conformity with the above specifications, properly blended and boiled together in a pitch boiler. The correct consistency shall be ensured by applying the following test:—

"*A sample of the mixture* cast in a suitable mould and cooled in water to 60° F., and maintained at that temperature in water, shall be of such consistency, that a column 1½ ins. in length and ½ in. in diameter, shall, when subjected to a uniform tensile stress of 5½ ozs. [including half its own weight], stretch to a length of 12 ins. in eight minutes without breaking.

"*Immediately before being* put on the road an equal quantity of fine shore sand heated to 400° F. shall be added to the pitch mixture, which shall then be kept continually stirred until spread."

The results in Liverpool have been very successful, but this has not occurred in all cases where a less rigid "specification" has been followed or where the methods and materials have not been suitable.

Failures of Pitch Grouting.—Some of the failures of pitch grouting have been due to one or more of the following causes: (*a*) insufficient consolidation of the road before the grouting was added; (*b*) insufficient filling of the interstices between the stones, thus leaving cavities or voids that were ultimately insufficiently protected by the grouting; (*c*) the cooling and "setting" of the grouting before sufficient penetration was reached; (*d*) stones of too large a gauge were employed[1]; (*e*) the stones were wet or even moist and consequently the grouting was incapable of adhering to them; (*f*) an insufficient quantity of grouting was provided in order to economise; (*g*) the pitch or other material used to form

[1] It has been authoritatively stated that with even 2-in. and 1½-in. gauge of stones loosely spread, the voids equal 46 per cent. of the mass, whereas, if the stones had been properly mixed with chippings or other filler, these voids would have been reduced to about 12 per cent.

the grouting was unsuitable, or the amount of sand added was too much or too little; (*h*) the stone was unsuitable as having too hard a surface for the grouting to adhere.

Road Board's Instructions.—For the guidance of surveyors and others who were engaged in constructing roads of this denomination, the Road Board issued some general directions which, *inter alia*, are as follows:—

After drawing attention to the necessity of the road, which was to be re-surfaced with pitch grouting, having a proper foundation, they recommend that the thickness of the surface coating of pitch grouted macadam, when finished and consolidated by rolling, should be 2½ ins. to 3 ins. for single pitch grouting, and for double pitch grouting the thickness should be 4 ins. to 4½ ins. for the two coatings combined.

The Stone.—The stone forming the coating should be "of approved quality," broken to 1½-in. gauge, and in addition to this, 10 per cent. of chippings of the same stone, varying from ¾ in. down to ⅜ in., should be provided for sealing after the grouting had been done.

The Pitch.—The pitch used should be that which is specified by the Board [see specification on p. 129], altered by varying the quantity of the tar oils as occasion demands.

They point out the great importance of the stones being absolutely dry before the grouting is applied.

The quantity of pitch required to grout a single coating, consolidated to a thickness of 2 ins., is estimated at 1¼ gallons per yard super; for 2½ ins. at 1½ gallons, and for 3 ins. at 2 gallons per yard super.

These quantities vary with different materials, and "care must always be taken to fill the voids". The pitch, after being melted in the manner recommended hereafter, must be raised to a temperature of 300° F., and clean, sharp sand, which has been raised to a temperature of 400° F., is then added to the hot pitch, and kept well stirred during mixing, and right up to the time of pouring it on to the road. Final rolling should be commenced immediately after the grouting has been done, and carried on as rapidly as possible before the grouting has had time to set. Then the 10 per cent. of chippings, mentioned above, should be spread over the whole surface, partly before the rolling is commenced, and the remainder during the process of rolling.

The above directions apply only to single pitch grouting. For double pitch grouting they are as follows:—

Double Pitch Grouting.—With regard to this, the Board's directions first drew attention to the desirability of this method in order to get a sufficiently thick crust of from 4 ins. to 4½ ins. in depth, where the traffic is heavy, and to the advantage of dividing this thickness into two coatings in order to ensure penetration.

The procedure is much the same as that already given for the single coat pitch grouting, except that the bottom layer should be of larger stones, slightly thicker than the top layer, and that the stones need not be of the hard quality required for the top layer. In pouring the pitch on the bottom layer it should not be brought up quite to the surface, but should lie about ½ in. below such surface, "with the object of providing a key for the upper layer". The estimated quantity of pitch required for this double grouted road is, for 4 ins., 3¼ gallons per yard super, and for 4½ ins., 3½ gallons.

Melting the Pitch.—The directions or instructions for melting the pitch are very complete, and are given in full as follows:—

"The pitch boilers of from two to three tons capacity should be charged with pitch, and about one-half of the proper proportion of tar oils. The fire should then be lighted, and thereafter a steady fire, with fire-doors closed, should be maintained, when, in from four to five hours, the pitch should be thoroughly melted. A bright fire should be kept until the pitch reaches a temperature of 300° F., when the remainder of the oils should be added, and the mixture thoroughly stirred; the fire-doors should then be opened, and the temperature of the melted pitch permitted to fall to 250° or 270° F. The pitch should then be ready for use, and in all cases should be thoroughly well stirred before being drawn off.

"In the event of bad weather stopping the work of grouting, the fire-door should be left open, the damper closed, and the temperature of the pitch allowed to fall to 200° F. It can be kept at this temperature for long periods with banked fires consuming about 7 lbs. of coke per hour.

"It is recommended that a suitable Fahrenheit thermometer with metal protection should be at hand to indicate the temperature of the melted pitch. Whenever the weather is favourable for the recommencement of the work, the pitch must be again raised to 270° F. by closing the doors and sharp firing.

"It is desirable that the boiler should be kept airtight when the pitch is being melted, by the use of airtight covers properly packed so as to make an airtight joint."

Specification of Pitch.—The specification for the pitch to be used for the grouting is as follows:—

"The pitch is obtained of the required consistency most conveniently by running it off from tar stills in which the distillation of the tar has been stopped at the point at which the residual pitch will give a penetration of 70 [or such other penetration as may be specified to suit climatic or local conditions] when tested at 25° C. [77° F.] on a standard penetrometer. Harder pitch may be softened or cut back, in the still or in a mixer at the tar works, to the extent necessary for it to give this penetration, by the addition of tar oil of the grade specified below.

"Where pitch of the required consistency is not thus directly procurable, it may be prepared by softening commercial soft pitch, as specified below, by the addition of tar oil as specified below. In preparing the softened pitch in this manner the tar oil is added to the pitch in the manner described under 'Instructions for Melting the Pitch,' in such proportions that the resultant softened pitch will give a penetration of 70 [or such other penetration as may be specified to suit climatic or local conditions] when tested at 25° C. [77° F.] on a standard penetrometer, with a No. 2 needle weighted to 100 grammes for five seconds.

"Pitch which has been procured of the required consistency directly from a tar distillery needs only to be thoroughly melted in the pitch heaters or boilers, but as a precaution against burning, 1 to 2 per cent. of tar oil may advantageously be put into the boilers with the pitch.

"Pitch which has been procured of the required consistency directly from a tar distillery shall not yield more than 4 per cent. of distillate below 270° C., or 518° F., on distillation as described below, and shall contain not less than 16 per cent., and not more than 28 per cent. of 'free carbon,' as defined below."

"**Commercial Soft Pitch.**—The pitch shall be derived wholly from tar produced in the carbonisation of bituminous coal, except that it may contain not more than 25 per cent. of pitch derived from tar produced in the manufacture of carburetted water gas.

"On distillation in a litre fractionating flask one-half to two-thirds filled, the pitch shall yield the proportions by weight of distillates stated below; the temperatures of distillation being read on a thermometer of which the bulb is opposite the side tube of the flask:—

"Below 270° C. or 518° F., not more than 1 per cent. of distillate.

"Between 270° and 315° C. or 518° and 599° F., not less than 2 per cent. and not more than 5 per cent. of distillate.

"The pitch shall contain not less than 18 per cent. and not more than 31 per cent. by weight of free carbon."

Tar Oil.—These instructions, or specifications, wind up with details as to the source and quality of the tar oil which are as follows:—

"The tar oil to be used is preferably a filtered green or anthracene oil, and shall be derived wholly from tar produced in the carbonisation of bituminous coal, or from such tar mixed with not more than 25 per cent. of its volume of tar produced in the manufacture of carburetted water gas.

"The specific gravity of the tar oil at 20° C. (= 68° F.) shall lie between 1·065 and 1·085.

"The tar oil after standing for half an hour at 20° C.

(= 68° F.) shall remain clear and free from solid matter (naphthalene, anthracene, etc.).

"The tar oil shall be commercially free from light oils and water. On distillation in a litre fractionating flask one-half to two-thirds filled, the tar oil shall yield the proportions by weight of distillates stated below; the temperatures of distillation being read on a thermometer of which the bulb is opposite the side tube of the flask:—

"Below 170° C. or 338° F., not more than 1 per cent. of distillate (light oils and water, if any).

"Below 270° C. or 518° F., not more than 30 per cent. of distillate (middle oils and light oils and water, if any).

"Below 330° C. or 626° F., not less than 95 per cent. of distillate (heavy oils, middle oils, and light oils and water, if any)."

This completes the reference to these "General Directions and Specifications relating to the Tar Treatment of Roads" which were issued by the Road Board in the hope that they would be useful to surveyors and others engaged in the work of road construction and maintenance, and there can be no doubt that these elaborate instructions, prepared by the Advisory Committee of the Road Board, of which I had the honour to be a member, if strictly complied with, should result in good roads of this description being constructed, as they should be dense in structure, and yet somewhat resilient, practically impervious to moisture, easily cleansed, offer but little resistance to traction, durable, easily opened and reinstated, make little or no dust, and should be practically noiseless under traffic, and the traffic can be turned on them immediately after they have been completed without causing them any damage.

As an example of actual work carried out on this system, the following particulars are practical and useful[1]:—

"**Pitch-grouted Macadam.**—This can be laid in single or double coatings according to the requirements of the traffic. In single pitch grouting the existing surface of the road is

[1] *Vide* "Main Roads Past and Present and Modern Methods of Construction and Maintenance," a paper read at a meeting of the Society of Engineers by Mr. Frank Grove, M.Inst.M. and C.E., Assistant County Surveyor of Surrey, April 13, 1915.

scarified and the excavated material, after being sifted to remove all stones below 1 in., is re-spread together with sufficient new granite or other suitable material of about 1½-in. gauge and rolled dry until the stone is fairly firm. The grouting mixture, consisting of pitch, oil, and sand, is then poured on to the partly-rolled surface, using as little of the mixture as possible to fill all voids to within about half an inch of the top of the stone, and the surface is then lightly sprinkled with clean ¾-in. chippings. Before the grout has time to set the roller is again applied and sufficient chippings added during the process of rolling, which is continued until the grout is squeezed up to the surface and becomes thoroughly cool and consolidated. After being thrown open to the traffic the surface is dressed with a further coat of pitch and oil or tar and chippings to secure a smooth and even waterproof face. Double pitch grouting is identical except that the aggregate is laid, grouted, and rolled in two separate layers. The material for the bottom coat is of 2-in. gauge and for the top coat 1½-in. material is used. The finished thickness of single pitch grouting is about 3 ins. and of double pitch grouting from 4 ins. to 4½ ins. The method of preparation and finishing is exactly similar in both cases. In preparing the grouting mixture all the pitch and half the oil is first placed into a 600 gallon boiler, which is large enough to heat, safely, about 500 gallons, and is heated to a temperature of 300° F., after which the remaining half of the oil is added, the mixture being thoroughly stirred during the process of heating. Clean, sharp sand, heated in sand driers to a temperature of 400° F., to which is added a very small percentage of Portland cement, is then mixed with an equal proportion of the pitch mixture in a dandy or portable mixing vessel, the mixture being stirred right up to the time of actual pouring upon the roadway, which is done as evenly and quickly as possible by means of ladles or pouring cans. As a rule, one pound of oil is generally found sufficient for every 10 lbs. of pitch, but great care must be taken that the mixture is not too brittle, which can be remedied by adding a further small proportion [about 1 in 50] of oil. A method generally adopted of testing the pitch mixture is to draw off a little, and, after allowing it to cool, a piece is held between the finger and thumb of both hands and stretched until it draws out to a fine thread at least 3 ft. long before breaking. The approximate quantity of pitch required for a consolidated thickness of 2 ins. is $1\frac{1}{4}$ gallons per yard super, for $2\frac{1}{2}$ ins., $1\frac{1}{2}$ gallons, for 3 ins., 2 gallons, for 4 ins., $3\frac{1}{4}$ gallons, and for $4\frac{1}{2}$ ins., $3\frac{1}{2}$ gallons. The cost works out at between 3s. 6d. and 4s. per yard super. The great drawback to pitch-grouted macadam is the extreme difficulty experienced in obtaining a perfectly regular distribution of the pitch mixture, any excess in quantity being followed by a tendency of the surface to corrugate and even pull in hot weather, whilst with an insufficiency of the mixture the surface is not rendered completely waterproof during the winter. For these reasons the surface seldom remains so good as well constructed tar macadam."

Notes on Tar Grouting.—The following "Notes on Tar Grouting Roads," written in 1911 by a well-known county surveyor, will be of interest:—

"Two prominent features mitigate against the success of tar grouting—moisture and dust.

"When commencing to tar grout, the surface of the old road should be carefully swept with brushes for the purpose of removing all dust or dirt before the new metal is applied. The stone must be absolutely clean when it is spread on the road. Stone grapes are therefore essential in separating the dirt from the stone, both in filling and spreading. A shovel and brush are likewise required to gather up and remove from the road any dirt that is amongst the stone. All stone should be tipped up on the road 6 ft. from the edge of the patch, and the whole of the stone must be lifted and spread with the stone grapes, the larger size stone being laid on the top.

"In the laying on of the stone one-half of the road should be coated at a time. The ends of the patches are to be tapered off with a 12 ft. taper at each end—the 12 ft. of the old surface, at the ends of the patch only, to be broken up with the scarifier before the broken stone is applied to the road.

"As to the size of stone for repairing a road carrying a mixed traffic, I prefer 2-in. H.B. whinstone or 2½-in. M.B., with all stone under 1½ ins. taken out. One ton of 2½-in. H.B. or 2½-in. M.B. whin should cover an area of 12 square yards. On roads, especially those with a wet foundation and carrying locomotive and motor-waggon traffic, I consider 2½-in. and 3-in. H.B. the most suitable sizes to use. One ton of stone broken to these sizes should cover 10 square yards. In no case would I recommend 1½-in. stone, other than for filling holes or patching.

"Immediately after the stone has been spread on the road the driver is to pass the roller backwards and forwards over the dry stone until the whole is compressed into a smooth surface. It will be found that the larger size stone requires more rolling than the smaller size. After the stone has been grouted with tar, etc., and when it is cold, the roller is to be run over the tarred surface three or four times for the purpose of impregnating the stone with the tar, etc. After this, chippings or ashes are to be sprinkled thinly over the tarred stone, and followed up by continuous rolling and brushing until proper consolidation is obtained.

"Acting on instructions given by the foreman in charge of the tar plant, the roller driver and flagman shall attend to the removal of the tar boilers to and from the road. In the bringing and taking away, the tar boilers shall not be turned round, either full or empty, on the newly tarred stone. It shall be the duty of the roller driver to see that the valves and injectors are closed so as to prevent the water from the engine getting on to the dry stone; nor shall any ashes or ash residue, in the cleaning of the engine fire and smoke-box be allowed to fall on to the dry stone.

"The man in charge of the tar tanks should give particular attention to the keeping of the tar boilers in good working order, and to see that there is no accumulation of dust or ashes in the furnace or flues. Special attention must be given to prevent scale or free carbon adhering to the bottom of the boilers. The only and sure method of preventing this sediment at the bottom of the tanks, and from the liquid boiling over, is by constant and frequent stirring. It also assists in quick heating, and produces that proper assimilation of the tar with the pitch and creosote oil so much desired. A hot and steady fire must be kept up to boil the liquid, and only when it has been heated to boiling temperature, 600° F., is the liquid to be spread over the stone.

"When the proportionate quantities of tar, pitch, and oil are put in a cold 320 gallon boiler, it will require 6 hours continuous heating to boil the mixture ready for the road. The time for heating a warm tank is much less, the latter taking from 3 to 3½ hours.

"In the pouring on of the liquid, the grouting should commence from the sides and work to the centre of the road. When the first half of the road is being grouted, a width of 18 ins. in the centre of the road should not be tarred. This will admit of the formation of a regular contour when the other half of the road is being coated with stone.

"The quantities of tar, pitch, and creosote oil for one charge of a 320 gallon tank are:—

Tar . .	1,000 lbs.	Approximately 2 barrels.
Pitch . .	1,100 ,,	
Creosote oil	90 ,,	Three 3-gallon cans.
	2,190 lbs.	

"Half of these quantities will charge a 150 gallon tank.

"In measuring these quantities it is well to bear in mind that a barrel of tar varies in weight from 432 lbs. to 502 lbs. To assist the foreman in charge of the plant the tar, pitch, and oil will be consigned to him. On the consignment note the number and net weight of tar in each barrel is given. There need be no difficulty in finding out the exact proportions of tar, etc.

"Taking the weight of a 320 gallon tank of hot liquid as 2,160 lbs., this gives 180 gallons for grouting, 2-in. H.B. or 2½-in. M.B. whin. This quantity should grout 12 tons or 144 square yards. For 2½-in. and 3-in. H.B. stone the 180 gallons will grout 10 tons or 120 square yards.

"As these are exact quantities, it is essential that no quantity of the liquid, however small, should be left in the tank.

"In the carting of the tar and oil, every care should be taken in the handling of the barrels, both at the stations and on the road. All barrels should be neatly stacked in rows on the roadside waste, well out of the way of the traffic and with the bung-holes at the top. To economise in the carting, where possible, all empties should be carted to the station on the same day as the full barrels are being brought to the road. To every twelve barrels of tar deposited there should be two barrels of oil and 2¾ tons of pitch.

"The pitch should not be deposited on the stone depots, or where the ground is covered with ashes, but on the grass.

"The chippings, gravel, or ashes for binding the tarred surface must be perfectly dry when laid on. Where ashes are used, all large scars or blinkers are to be broken into small pieces with a hammer before being spread on the road.

"As the tarred stone is to be rolled before the binding material is applied, it will be found that a much less quantity is required, and in no case should it exceed 8 tons of binding to every 100 tons of broken stone.

"The men shall start work at 6.45 a.m., leaving work at 5 p.m., allowing fifteen minutes for breakfast and one hour for dinner. Any time worked beyond these hours shall be paid as extra by the hour.

"The attendant on the tar boiler shall start work at 4 a.m. and leave at 2.15 p.m., after having allowed an hour and a quarter for meals.

"The hours for Saturday are from 6.45 a.m. to 12 noon, allowing fifteen minutes for breakfast.

"These hours apply to all men, including carters, roller driver, and flagman, employed at tar grouting.

"The foreman shall keep an account of all tar, oil, pitch, coal, and tools used, and shall return all empties to the sender. He shall also return each ticket of coals for the tanks, tar, pitch, and oil, to the divisional surveyor, with his signature on each ticket, when he returns his own monthly journal. He shall likewise forward to the county surveyor, on a printed postcard, the number of empty barrels returned.

"A printed daily statement will be sent to the foreman in charge of the plant, so that he may fill in the following particulars:—

(*a*) Names of workmen employed with tar tanks.
(*b*) Number of hours worked.
(*c*) Consumption of tar, pitch, and oil, also coal.
(*d*) Quantities of chippings used.
(*e*) Area of road grouted and quantity of stone."

The above instructions are practical and helpful, and might be followed to-day although they were written nine years ago.

Another Description of Pitch Grouting.—The following description of pitch-grouted roads in a town in Lancashire will also be of interest:—

"Penmaenmawr syenite, broken to a 2⅝-in. gauge, carefully screened and free of all dust, laid 5 ins. thick on existing surface after careful sweeping or scraping. Then rolled with a 15 ton roller until creeping has stopped. It is then about 4 ins. deep [a strip 20 lin. yds. by 4 yds. wide = 80 sq. yds., takes about a half-hour rolling]. Whilst dry-rolling takes place the last strip of similar area is being tarred. The tar mixture is put on the road with ladles till the rolled macadam, which must be perfectly dry, is well grouted, then ½ in. of Penmaenmawr syenite chippings ¾-in. gauge laid on surface and rolled for a half-hour till a smooth surface is obtained. The roller fresh from rolling the dry macadam has its wheels covered with dry dust which prevents adhesion.

"The tar mixture is as follows:—

"Pitch, 30s. a ton on site, weighs 12 lbs. to the gallon. One ton of pitch with 40 gals. of creosote oil is placed in the boiler of 360 gals. capacity which is about half filled. Too much pitch makes mixture too stiff and brittle, whilst an excess of oil makes it too soft. In order to find right temper, take a handful of the mixture, after cooling in water to 60° F., and pull it out. It should stretch to 3 ft. and bend double without breaking. Every boiling should be thus tested three times, viz. at starting, in the middle, and towards the end, as oil tends to evaporate. When temper is satisfactory take 1 cwt. of the mixture and put it in an 18 gal. bucket, say 20 ins. deep and 18¼ ins. diameter. It will occupy 11 ins. in depth. Add 1½ cwts. of washed river sand or sea sand free from dust, dry, and at a temperature of say 120° F. [as hot as can be held in the hand]. This fills the bucket. Then stir with an instrument like a drainer's spade [? a grafting tool], and then ladle out hot on to the road, and it penetrates the interstices and cavities. If weather becomes wet the operations must be stopped.

"The following gives the quantities of the various materials used:—

1 ton pitch for every 54 sq. yds.
1 gal. creosote for every 1·8 sq. yds.
1 ton granite for every 7·2 sq. yds.
1 " " chips for every 58 sq. yds.
1 " sand for every 35 sq. yds."

Before closing these remarks on pitch grouting it may be interesting to compare an American specification for carrying out "Tar Grouting" as it is called "over there".

American Specification for Tar Grouting.—"(*a*) The top course stone, consisting of the run of the crusher, from screenings to and including 2-in. stone, shall be spread on the bottom course to such a depth that it shall have, when completed, the required thickness, after which 1¼ gallons of bituminous material shall be evenly spread over the surface. . . . After the bituminous material has all been applied, sufficient additional screenings shall be added to the surface to fill the voids and cover the road thinly. . . . The loose screenings shall then be swept off with hand brooms, after which ⅓ gallon of bituminous material to each square yard shall be evenly spread over the surface in the same manner, and immediately thereafter be covered with ⅜ in. of dry screenings.

"(*b*) As soon as the second course has been sufficiently compacted, and the voids filled with the finer sizes, the surface shall be thoroughly cleaned of all surplus fine material by brooms, or such other measures as may be necessary to secure the result. . . . On the warm, dry, and cleaned second course shall be spread a coat of pitch compound in such quantity as will thoroughly saturate the prepared surface. . . . After the pitch compound has been applied, the pitched surfacing will be lightly coated with clean screenings, sand, or stone chips.

"(*c*) Upon the Telford foundation there shall be spread a binder course of stone, which shall pass a 2½-in. screen and pass over a ¼-in. screen. This course shall be thoroughly rolled, and sufficient screenings added to make a thoroughly compacted and smooth surface. . . . Upon this surface shall be evenly spread 1½ gallons of bituminous material to each square yard. . . . Immediately thereafter a course of 1½ in. run of the crusher stone shall be evenly spread on the surface. . . . A layer of the same bituminous material, ½-gallon to the square yard, shall be spread evenly over the surface, and the same covered with sufficient dry, dustless screenings to take up all excess bitumen.

"(*d*) The second course of 1½-in. stone shall be spread and rolled as directed. The voids shall then be filled with dustless screenings and ¾-in. stone until about 75 per cent. of them have been filled. . . . Bituminous cement shall then be spread in a uniform layer at the rate of ⅓ gallon of bitumen per square yard. A layer of ¾-in. stone and dustless screenings shall be spread at once, and the road rolled. A second application of bitumen shall then be made, covered at once with a coat of screenings, and the road again rolled.

"(*e*) Upon the properly prepared bottom course there shall be evenly spread 1½-in. stone to the depth of 3 ins. The course shall be dry-rolled, the surface being open or porous in order to allow the penetration of the hot binder. Directly after the application of the binder, clean, dry ¾-in. stone, free from dust, shall be spread over the surface in sufficient quantities to fill the surface voids completely. . . . A seal or flush coat of the hot binder shall be uniformly distributed over the whole surface. . . . Clean, dry ⅜-in. stone chips shall then be spread over this seal coat in just sufficient quantities to take up all excess binder, leaving a slight excess of stone chips to protect the surface while setting up."

Having thus far dealt with "Pitch Grouting," it will be necessary now to turn to the question of what is known as—

Tar Macadam.—Reference has already been made to the early methods for the construction of this material, and need not be repeated.

Sidcup Trials.—In the well-known "Sidcup Trials" arranged by the Road Board, in conjunction with the Kent County Council, in 1911, on the London-Folkestone Main Road, several "specimens" of this description of construction were laid.

One of these was as follows:—

The aggregate consisted of Kentish ragstone, in the following proportions:—

75 per cent. of 2½-in. to 2-in. gauge, and 25 per cent. of smaller material, the top surface being finished with stone, varying between 1 in. to ⅝ of an inch, which was used to seal the surface.

The stone was dried and mixed with boiling tar in a rotary tar macadam mixing machine, kept hot during the whole time of mixing. The material was then laid cold on the surface, which had been excavated for the purpose, and was rolled into place. This stood fairly well, but was disturbed by being cut through for a water main, and was re-laid with single pitch grouted macadam in the year 1913.

Another "sample" was made with blue Guernsey granite, and mixed in the same manner, but the finished surface was given a surface coat of Clare's special bituminous composition at the rate of 10 gallons per ton of stone. This stood very well until 1915, when it was reported as being "practically worn out".

A third sample was made with Penmaenmawr syenite, broken to the following sizes:—

59 per cent. of 2-in. gauge, 20 per cent. of 1-in. gauge, 12 per cent. of ½-in. gauge, and 9 per cent. of ¼-in. gauge.

The stone was "crusher run," graded with only its dust taken out. This mixed aggregate was coated with tar altogether, and $\frac{1}{4}$-in. seal coat was added at the rate of 40 super yards covered per ton of material. This was never quite satisfactory, as the special tar mixture began to flow in the hot weather succeeding the construction of this section, which denuded some of the stone of this matrix, and it was also disturbed by the laying of a water main. In 1914 it was relaid with a wearing surface of bitumen and shingle on a sub-crust of granite, grouted with a pitch grouting.

Reasons for Failures.—None of the tar macadam samples appear to have been very satisfactory with the Sidcup trials, which may have been due to the following causes:—

(1) The lengths were only about 100 yards of each trial section, thus giving little scope for machinery on any large scale being employed.

(2) The traffic on this road is very severe, some 3,500 tons a day.

(3) In some cases this traffic had to be borne on the half-width of road during construction.

(4) The various contractors were, no doubt, anxious to keep the cost of construction as low as possible.

(5) It is possible that some of them did not quite realise the importance of these trials.

The Wandsworth Trials.—This is partly confirmed by the subsequent "Wandsworth Trials," which were made for the purpose of comparing the rates of wear of tar macadam made with tarred granite and tarred slag. The road selected was the London-Portsmouth road in the Kingston Vale, where the traffic is heavy, about 5,700 tons a day. One of the sections made with tar macadam may be described shortly as follows:—

Guernsey granite, coated with special bituminous composition, spread in two layers, the bottom layer graded from $2\frac{1}{2}$ ins. down to $\frac{1}{2}$ in., and the top layer $\frac{3}{8}$ of an inch topping, sufficient to bind the larger material. The surface was finished with fine chippings. The material was heated and mixed in a machine on the site, and was spread and rolled *cold*, as it was allowed to "mature" before being laid. This has been quite a satisfactory trial, and, notwithstanding the heavy traffic on this road, has stood fairly well.

A length of exactly similar material was also laid, except that it was spread and rolled *hot*, and does not appear to have been so satisfactory as that which was laid and rolled *cold*. Indeed, it was really not at all satisfactory, as it has subsequently been re-surfaced with other forms of construction. But it is interesting to see that these trials of tar macadam gave much more satisfactory results than those laid in the Sidcup trials.

The Fulham Trials.—Some further trials were also carried out at Fulham, in various streets, under arrangements made with the Borough Council and their Surveyor, Mr. F. Wood, M.Inst.C.E.

About a dozen sections were laid; the descriptions of their construction are very short and inadequate, and are as follows:—

No. 1. Composed of 60 per cent. granite and 40 per cent. Trinidad Lake bitumen. Consolidated to a thickness of 3 ins. in the centre and 2½ ins. on the sides. In 1915 the report on the construction was not very good, and that it required reconstruction.

No. 2. Composed of 60 per cent. slag and 40 per cent. Trinidad Lake bitumen. Laid as in No. 1. Report the same as in No. 1.

No. 3. Composed of 60 per cent. clinker and 40 per cent. bituminous matrix. Reported in 1915 as being somewhat bumpy and wavy, but otherwise in good condition.

No. 4. Composed of 60 per cent. gritstone and 40 per cent. bituminous mixture. Report in 1915 much the same as No. 3.

No. 5. Composed of 60 per cent. Kentish rag and 40 per cent. bituminous matrix made up of 80 per cent. bitumen and 20 per cent. tar compo. Reported in 1915 as a few places showing signs of disintegration, otherwise in good condition.

No. 6. Composed as in No. 5. Reported in 1915 as being in good condition, a little wavy and bumpy.

No. 7. Same as Nos. 5 and 6, except that granite was used instead of Kentish rag and the bituminous matrix was made up of 60 per cent. bitumen and 40 per cent. tar compo. Reported in 1915 as being in fair condition, a number of depressions, some showing signs of disintegration, and a little wavy and bumpy.

No. 8. Composed of 60 per cent. granite and 40 per cent. bituminous matrix made up of 70 per cent. bitumen and 30 per cent. compo. Reported in 1915 in fair condition, a number of depressions, some showing signs of complete disintegration. Not quite so good as No. 7.

All the above sections were laid and consolidated to a thickness of 3 ins. in the centre and 2½ ins. on the sides.

No. 9. In this section the foundation was old tar macadam and bitumen laid in two layers, consolidated to a thickness of 2½ to 3 ins.; the bituminous matrix coating was consolidated to 1 in., the surface after consolidation being brushed with dry cement.

The result was not satisfactory, the bituminous coating wore through the sub-crust, the rest was wavy and bumpy, it had lost its formation and it was reported that the greater portion required reconstruction.

No. 10. Much the same construction as No. 9. Reported that a short length needed re-surfacing, otherwise in fair condition, though somewhat wavy and bumpy.

No. 11. Composed of 60 per cent. granite and 40 per cent. bituminous matrix made up of 80 per cent. bitumen and 20 per cent. tar compo. The report was, poor condition, very wavy and bumpy and a number of depressions, and that it required surfacing with a wearing surface.

No. 12. Same as No. 11, except that Kentish rag was used instead of granite. The report was, good condition, a little wavy and bumpy.

Report on Fulham Trials.—The results of these trials are not very enlightening, but Mr. Wood, who conducted them, and had an opportunity of watching their behaviour, came to some conclusions which are valuable and may be condensed as follows:—

(1) That such materials as limestone, ragstone, gritstone, and clinker refuse, when of such size as makes them liable to be broken by the traffic to a smaller size, are unsuitable as a surface covering.

(2) That when they are covered with a bituminous coating, however thin, they are satisfactory.

(3) That granite is more satisfactory, but that the size should be reduced from the size used in these trials, as they are liable to move under the traffic.

(4) The aggregate should be in the lesser proportion to the matrix, e.g. instead of being 60 per cent. aggregate and 40 per cent. matrix, they should be 30 to 40 per cent. aggregate and 70 to 60 per cent. matrix, in order that the stones "should have a greater chance of being embedded in the finer material".

(5) That the material mentioned in No. 1 above will do, if mixed with suitably prepared bitumen and tar, the size of the material being not more than 1¼ ins.

(6) That slag is better than the soft stones but inferior to the granite sections.

(7) No advantage in mixing tar with bitumen.

(8) That the thicknesses of 2½ ins. and 3 ins. provided for the sections is sufficient, provided the foundations are sufficiently strong.

(9) That most of the sections would have been satisfactory if subjected to lighter traffic.

It is rather to be regretted that more minute details were not given of the methods of construction of all the trials, at Sidcup, Wandsworth, and Fulham, as in some cases it is difficult to follow them, but they are given above as examples of what was done about ten years ago and as a guide to pioneers in the construction of modern roads. It is evident, also, that in all undertakings, especially with regard to roads, we learn a very great deal by failures, and that the best, if not the only test of a suitable road construction is its actual behaviour under various forms and conditions of traffic; in other words, the proof of the pudding is in the eating.

Controversy as to Granite for Tar Macadam.—It is impossible, even now, to say what is the best form of construction of a tar macadam road, and it is interesting to note that, within the last few years, a considerable controversy has been raised as to whether it is possible to coat broken granite with tar, as the surfaces are alleged to be too dense and smooth for the tar to properly adhere. There have been failures, no doubt, with tarred granite macadam, and there have been successes. One of the advocates of tarred granite wrote, *inter alia*, as follows:—

"In my opinion the early failures of tarred granite macadam, and it is upon these very early failures, for obvious reasons, that most opinions have been formed, have been due to the lack of knowledge of, not only the quality of the tar that should be used, but also of how far the stone should be graded and efficiently dried . . . ; the following points should be carefully considered: (*a*) Grading the stone so that every interstice is filled and there is no movement of the stone after the road is laid. (*b*) Properly drying the stone. (*c*) Using a carefully prepared tar of high viscosity. (*d*) The surface should be properly sealed, and, in my opinion, no granite tar macadam should be laid less than 3½ ins. thick."

On this controversy another road engineer made the following remarks:—

"The matrix or binder should be 'bituminous,' and the proportions should be 'sufficient,' but not in excess. The tar or bituminous binder must be carefully distilled and 'treated' before being used. The granite should break with a rough fracture or the tar will not adhere. It must, of course, be absolutely dry, but not over-heated.

"The foundation of the road should be strengthened and well drained. Dry weather is important whilst the tar macadam is being laid, any mud or slurry left on the formation surface is fatal. The layers should not be laid too thin. For single coat work not less than 3 ins., consolidated. Over rolling should be avoided, and the roller should not exceed 10 tons. The surface must be finally sealed with tarred chippings, ¾-in. to ½-in. gauge. Over-heating is often the cause of failure.

The seal coat does not always fill the voids, another cause of failure. Limestone seems to enter into a sort of 'chemical affinity' with tar and so does slag, but basalts do not."

Another road engineer says:—

"I have found that the most satisfactory results have been obtained by laying down the first coat mixed in the proportions of two parts of $2\frac{1}{4}$-in. and one part of $1\frac{1}{4}$-in. tarred granite to a consolidated thickness of $3\frac{1}{2}$ ins. or 4 ins., and sealed with a covering of $\frac{3}{4}$-in. to $\frac{1}{2}$-in. tarred granite. The whole then thoroughly consolidated and lightly sprinkled over with dry granite chippings. In order to ensure success the surface should be tar sprayed within six months, and kept properly sealed from time to time as required."

Another well-known engineer said:—

"Granite tarred macadam has also been tried, with but very few satisfactory results. The aggregate does not appear to be sufficiently porous or the surface sufficiently rough to retain the compound, the result being that under heavy traffic the material loosens and the surface becomes uneven. It does not seem practicable to keep a waterproof surface through the winter where the traffic is considerable, so it would appear to be only suitable for light traffic in exposed situations."

Summary of Controversy.—There are many points to be considered with regard to this controversy, as to the desirability or not of using granite as an aggregate for tar macadam. So much depends on the skill and observation of the road builder, and whether he used ordinary tar or some of the well-known and tried trade compositions. Then, again, how can a failure be defined? Does it mean the complete disintegration of the surface, or merely that it has become deformed, or wavy, or bumpy, or that the surface is not properly sealed, or that the tar or composition does not adhere to the stones? The amount of traffic on the road in question also requires consideration, and whether a softer stone than granite would have survived the traffic. No doubt, if there was an excess of voids or interstices between the stones, they would be liable to movement and inter-attrition, but this could have been avoided by a proper grading of the aggregate whether of granite or other stone. If not properly sealed the surface could be sealed with a tar dressing, and some engineers affirm that tar spraying or painting is necessary at least once a year, or even twice a year, for all descriptions of tar macadam roads, irrespective of the material from which the aggregate is formed.

The main point of contention against granite is that, in order to properly dry it, it must be heated to a considerable temperature, and that in over-heating it, it becomes brittle and splits up under the traffic. If, on the other hand, it is not so heated, the centre of the stone cools, and, in doing so, the tar is ejected from the surfaces of the stone. It is also contended that, owing to the hard nature of granite and the smooth nature of its surface, there is never any affinity between it and the tar, which, consequently, cannot properly adhere. The most serious contention is, however, that experience has now shown that whenever tarred granite has been used, "anxiety is always caused in the early spring, due to interstices showing between particles of the stone which can only be sealed by surface tarring". It has also been frequently observed that, on opening a road for any purpose, a large number of stones, if of granite, appear to be completely denuded of tar.

On the whole, therefore, the concensus of opinion as to the use of granite as an aggregate for tar macadam is that it cannot be recommended.

Various Methods.—Before passing on to describe other descriptions of bituminous roads it will be interesting to describe shortly the various methods that have been tried, with more or less success, since this method of construction commenced; the following may be taken as a type:—

"The road was scarified and a coat of new metal spread in the usual manner. This was steam rolled with the application of a little water to bring up the binding material from the old road below in order partially to bind the new macadam. When the metal presented a clean and even surface and before the binding material from below reached the top, a thin layer of ¼-in. tarred chippings was spread over and swept into the interstices, and the road was again steam rolled until thoroughly consolidated. A layer of tarred chippings [¾-in. to ¼-in. gauge], about ¾ in. in thickness was then spread and rolled to a finished surface. This was afterwards tar painted with a view to making the road practically waterproof. Most of the roads made in this manner have been tolerably clean during the winter months, and they are practically dustless. In one or two cases this method of construction has not been satisfactory, but these were the exceptions, and further experience during the coming summer will probably result in complete success."

The above method was tried and adopted in a well-known residential town in England, the traffic is not very severe.

Another description of work, carried out on a main country road subjected to considerable traffic, will also be of interest, and is as follows:—

The road was scarified and removed to a depth of 3 ins. and the weak places made good, consolidated, and the surface rolled and shaped to a contour of 1 in 36. The scarified metal was taken to a portable mixing plant as close to the work as possible where it was dried, heated, and screened, and then mechanically mixed with a "pitch and oil" composition.

The old macadam, thus treated, formed the base or strength crust which was laid hot on the road and rolled and consolidated to a depth of 2½ ins. The wearing crust was also laid hot to a consolidated depth of 1¼ ins. and was composed of the following materials:—

	Lbs.	Per Cent.
Sand	616	61·6
Chippings	124	12·4
Filler	100	10·0
Matrix	160	16·0
	1,000	100·0

The filler consisted of Portland cement of which about 75 per cent. passed through a 200 mesh sieve. The composition of the matrix was as follows:—

	Lbs.	Per Cent.
Bitumen	9,680	87·5
Heavy oil	1,080	9·8
Light oil	300	2·7
		100·0

Plant for Construction of Bituminous Roads.

The plant for mixing this wearing crust material was not fixed near the work but near a railway siding. It consisted of two "Rotoric" sand dryers, elevators, screen, hoppers, etc., and two bitumen heating tanks each of 1,000 gallons capacity. The sand was mixed by hand on a concrete banker in proper proportions and the percentage of granite chippings added. It was then heated in the machine to a temperature of 550° F. and was then mixed with the bituminous mixture which had been previously heated and well agitated by air pressure, and the filler is added and the mixture was ready for transportation to the road, which it reached at a temperature of about 350° F.

The following table gives the proportions of the sand, the aggregate, and the bitumen, taken from a sample of this wearing crust whilst it was being laid:—

	Sand Mixture.	Heated Aggregate.	Carpeting Mixture ready for Laying.
	Per Cent.	Per Cent.	Per Cent.
Bitumen	—	—	11·7
Sand passing 200 mesh sieve	0·9	9·0	11·5
,, ,, 100 ,, ,,	5·3	10·0	12·2
,, ,, 80 ,, ,,	6·4	8·0	9·8
,, ,, 50 ,, ,,	48·8	38·0	33·1
,, ,, 40 ,, ,,	24·0	19·0	10·3
,, ,, 30 ,, ,,	12·0	6·0	4·7
,, ,, 20 ,, ,,	2·6	3·0	3·2
,, ,, 10 ,, ,,	—	3·0	2·5
Retained on 10 ,, ,,	—	4·0	1·0

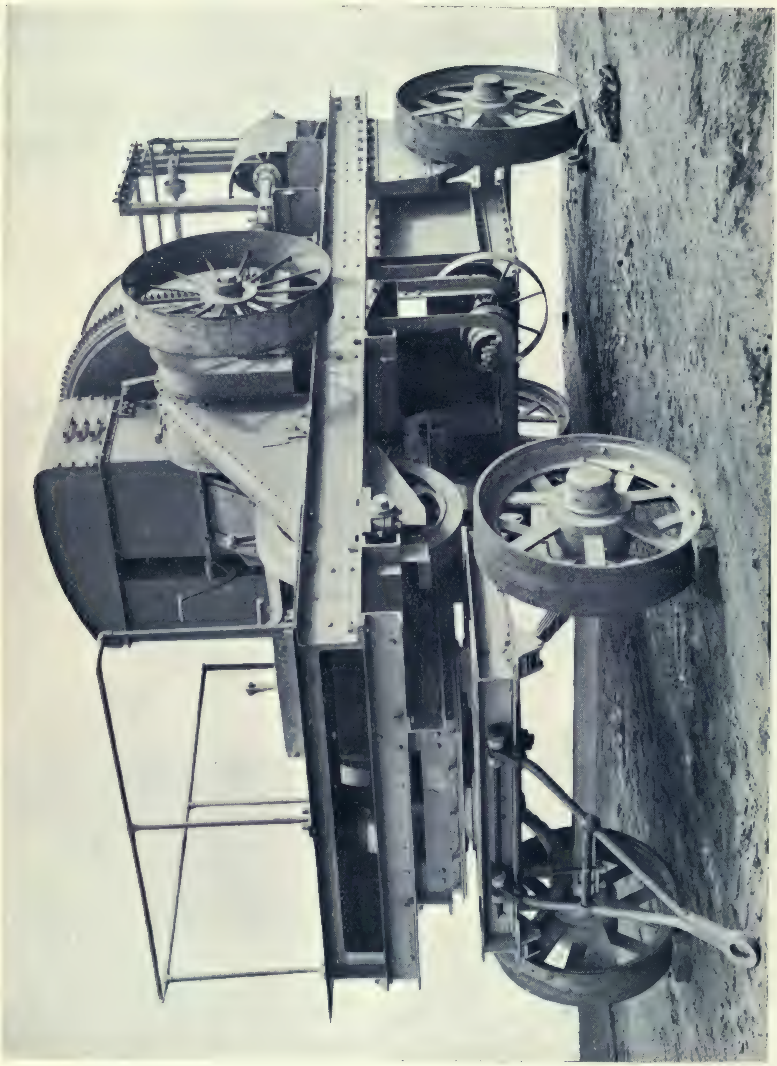
The above description is interesting inasmuch as that use was made of the old macadam taken from the road surface in the preparation of the bed for the new surfacing. It was found that this old macadam contained the proper proportions of sizes for the aggregate without any further mixing, and that the result formed an excellent strength crust of a homogeneous character.

Plant for Construction of Bituminous Roads. — The machinery employed for drying and heating the aggregate, and for mixing the materials with the heated bituminous compounds are various in design, both for ordinary "tar macadam" roads and for "carpets" or wearing crusts. The Plates X., XI., and XII. are types of various kinds and need no special explanation.

Examples of tar macadam roads might be given to any extent, but before leaving this subject the author considers it desirable to give a short description of the method pursued by Mr. Arthur Gladwell, the Surveyor to the Eton Rural District Council, in the early days when this kind of road construction was beginning to be introduced. This description is taken from the author's notes which he made after an inspection, in 1908, of a road near Slough, which Mr. Gladwell was then engaged in re-surfacing.

Gladwell System.—Having made good all irregularities in the surface of the road it was then well brushed and left solid, clean, and dry. A bituminous matrix or binder has in the meantime been prepared, consisting of thoroughly dried granite chippings, free from dust, and of a size that will pass all ways through a ¼-in. mesh sieve. These chippings are then heated to a temperature of about 150° F., and when still at about 100° F. are mixed with a specially prepared bituminous compound ["Tarvia" in this case] which had been previously heated to a temperature of about 170° F. About 15 gallons of this compound to a cubic yard of chippings was being used. The "mixture" was then left to cool and mature for a few days, and was then spread on the prepared surface of the road in a thin layer, using 1 cubic yard to every 46 square yards of road surface. On this was spread a single layer of 2-in. broken road metal, which was rolled until the binder had thoroughly worked up between the stones. Then a small quantity of the binder was sprinkled over the surface and lightly brushed into the voids and interstices between the stones, the roller continuing at work all the time until the surface was thoroughly solid. Then "Tarvia" was spread over the surface by means of a hand machine, and whilst it was still viscous, dry granite chippings were sprinkled over the surface and the rolling continued until the surface was thoroughly sealed and solid. The road was then ready for the traffic.

Plant for Construction of Bituminous Roads.



Tar Macadam Mixing Machine.

The author gives another report in his possession by an independent road engineer, who also inspected Mr. Gladwell's process on another occasion, and stated as follows:—

"Mr. Gladwell uses as a matrix quartzite [from Cherbourg], broken and screened to a ⅜-in. guage, dried and heated to about 80° F., and then treated with 'Tarvia' which has been heated to over 300° F. He slightly scores the surface of the road requiring re-surfacing and lays this matrix about ¾ in. to 1 in. in depth. On this is laid dry the road metal [granite], broken to a 1¾-in. to 2-in. gauge, then this is lightly rolled [6-ton steam roller], which drives the metal into the matrix which is squeezed up between the stones. It is then 'sealed' with a very thin coating of 'matrix,' sanded with chippings, and again lightly rolled. The surface is then 'sprayed' with hot 'Tarvia' by means of a small hand machine, then dusted with quartzite chippings, the road again very lightly rolled, and traffic is allowed on it at once.

"The matrix consists of about 13 gallons of 'Tarvia' to 1 ton of chippings. Cost about 1s. 6d. per square yard all told. He claims the importance of using 'Tarvia,' which is gas tar twice distilled and some 'secret' compound added. It appears to oxidise and become fairly hard on the surface of road when exposed, but remains viscous and resilient underneath, and seems to take up the 'shock' of the traffic. He says it is never slippery in either wet or frosty weather, and that snow seems to melt more quickly on it than on ordinary macadam roads."

At the time this method attracted considerable attention, and was looked upon with considerable favour, so much so that an eminent road engineer was reported to have said that the roads of the future need "no longer be known as macadamised roads but as Gladwellised roads!"

The author was himself greatly struck with the possibilities of this form of bituminous road surfacing, and has wondered why it has not been more generally followed. Some of these roads so treated by Mr. Gladwell have lasted quite seven years with only an occasional "tar refresher" with some granite chippings to restore the surface, and, as he says, "this simple process can be repeated *ad infinitum*," and this was on a road subjected to considerable traffic.

Mr. Gladwell was unable to continue this description of work during the War as he had to give undivided attention to the maintenance of his roads and their surface tarring, but he intends to continue his process at an early date. He expresses the opinion as to why his system has not been more generally adopted to—

(1) It was not sufficiently demonstrated to others. (2) Surveyors were disinclined to experiment on new systems with their own untrained men, but preferred to use other systems advocated by contractors who prepared the material and carried out the work with their own well-trained men. (3) Some of the early failures were due to over-rolling with too heavy rollers. He was unable to persuade surveyors that the work was much better done with a 6-ton roller than an 8-ton roller, and that about one-sixth of the amount of rolling required to consolidate a water-bound granite macadam road was all that was necessary for his system.

In this latter contention Mr. Gladwell was "prophetic," as very modern practice is now making certain classes of bituminous surfacing and "carpets" with no rolling at all, but only hand trowelling!

Drummond and Crompton System.—The most recent method for re-surfacing a road is that which may be called the "Drummond-Crompton Process," which is of peculiar interest as it is the latest method to be tried in the developments which are taking place in modern road construction.

The description of this process may be described shortly as follows [1] :—

The materials required are said to consist of a sufficient supply of good hard stone, either granite, whinstone, or basalt, serpentine or quartzite, or in some cases hard limestone, all broken to a 2-in. standard gauge. With this is required 20

[1] *Vide* "Memorandum on the Repairing of the Road Surfaces of the United Kingdom," by Robert Drummond, County Surveyor, First District, Renfrewshire, and Colonel Crompton, C.B., R.E., issued by the Roads Improvement Association in 1918.

per cent. of ¾-in. and 10 per cent. of ⅜-in. chips of the same class of stone, and it is stated, "the flakier these chips are the better they will suit the purpose of wedging the 2-in. stones". The old surface of the road is prepared by light scarifying near the haunches, but, as a rule, the centre or crown should "not be touched by the scarifier".

If there are any pot-holes, or ruts, or any deformation of the surface, these should be made good before the work of re-surfacing proceeds.

The 2-in. metal is then carefully and evenly spread on the surface thus prepared, and is rolled slowly and carefully so as to merely set the metal in place, and no traffic of any kind should be allowed to pass over this metal when once spread.

The ¾-in. chips, mentioned above, should then be "carefully spread over the once-rolled surface and the chips afterwards brushed to and fro until they fill all the interstices so as to pack or wedge the spaces between the stones".

This operation appears to be the *crux criticorum* of this new method as it requires considerable care and skill to carry it out successfully. It appears that two men are required, who stand on opposite sides and so brush the chips against each other that they stand up on end and fall lengthwise into the cavities between the metal, like wedges. Hence the necessity for the flakey chips mentioned above.

After this operation has been carefully carried out the roller is passed over these chips, which apparently stand up "like quills upon the fretful porcupine," which presses them downwards, so as to wedge and interlock the surface in "a very perfect manner".

It is urged that "in all movements of the roller it is better that the roller pass clear over the coating of the metal that is being operated; the engine of the roller should never be started or reversed until it is clear of new metal". The first part of the above instruction is not very explicit, but it is evident that in a rather delicate operation such as that described as essential for the locking of the chips into the surface, excessive care must be exercised in the rolling.

The grouting then follows, which appears to be effected by pouring the mixture, described below, from the usual pattern of spout cans with flat spreading trays hung to the spouts, which gives a spray of at least 9 ins. in width.

With reference to the composition of this grouting it is stated as follows :—

"One square yard should take about 1 gallon of grout, or from 8 to 12 gallons per ton of metal, according to strength of surface required. This grout should be a pitch and tar mixture mixed in such proportion that it sets when cold as a pitch which is plastic but not brittle at 32° F. The pitch and tar used should be preferably to Road Board specification for pitch and for tar No. 2. It is usually found that a greater proportion of tar or heavy oil [anthracene] must be added to the pitch in the north than is found necessary in the south of the United Kingdom."

And with regard to the temperature they say :—

"It is most important that the temperature of the grout when it leaves the spout of the pouring cans should not fall below 300° F. A thermometer should be provided to test this occasionally when the mixture is in the cans; it follows that the temperature in the tar boilers should be higher than this—probably 350° F.—but in the south where there is usually a greater proportion of the lighter oils present in the tar, some additional anthracene or heavy tar oil should be added from time to time, otherwise the mixture will become too brittle when cold.

"Immediately after the grouting is finished it should be followed by the spreading of the ⅜-in. or ½-in. chips, well brushed in so that all the interstices are thoroughly filled.

"Further rolling should then follow until the surface is quite cold. The traffic can be turned on about twelve hours after this final rolling has been completed."

The following observations complete the instructions from which these particulars are given :—

"When the metal is laid in half widths, it is better to lay the first width about one foot over the centre, leaving this foot untreated; when the second width is laid this loose foot of metal, which has become bespattered by passing traffic, should be shovelled away to the outer margin of the second side where the dirt on it does less harm, and its place taken by the new metal. In this way a good clean joint in the centre of the road can be obtained at a minimum of labour and trouble.

"After several consecutive lengths have been dealt with on the one side the traffic can be diverted on to it and the other side completed as above.

"When the above conditions have been observed, especially as to the high temperature at which the grout should be poured, roads have been laid in the winter in Scotland in frosty but dry weather at a temperature several degrees below freezing-point, and excellent results have been obtained at a time when road operations are usually suspended and roadmen are unemployed."

The author has not had an opportunity of inspecting any road treated in this manner, but the process appears to be conceived on sound lines, and if the chips are found to enter the cavities in the manner stated, there is no doubt that a road surface of good strength and well sealed should be the result.

Other Methods.—Before passing on to deal with tarred slag as an alternative to tarred granite or other stone, it will be of interest to describe some of the other methods which have been tried from time to time with more or less success.

The following, for instance, is taken from a specification for laying "Granastik" on a well-trafficked road near London:—

Granastik.—To every one part of mineral matter seven parts of silicious grit and to this silicious grit and mineral matter 10 per cent. of pure bitumen to be added. To every ton of refined fluxed asphalt, as above, 20 cwt. to 21 cwt. of Guernsey or other approved granite chippings to be added.

The aggregate of lower coat to be dried and heated to about 300° F. by hot air in a suitable machine, the fluxed natural asphalt, heated to the same temperature, to be added to the aggregate and the whole mass automatically mixed together until each particle of aggregate is thoroughly coated. The whole mass is then to be withdrawn from the machine, laid on the road, raked over to the required thickness, and consolidated and adjusted to camber by rolling with a 10-ton steam roller.[1]

The aggregate of upper coat to be dried and heated to about 300° F. by hot air in a suitable machine, and add to same asphaltic composition, heated to a temperature of about 300° F. in a mechanical mixer, the whole to be automatically stirred for about one hour. The material then to be withdrawn and poured over the lower coat and worked into position with wooden floats by hand labour. As the material sets it is to be sprinkled with sand and finished with wooden floats.

The cross-fall of the road, when completed, as measured between the centre of the road and channel shall be 1 in 32. The contractor shall supply and lay "Granastik" bituminous paving in two coats to a minimum thickness of 1½ ins. in channel and 2½ ins. on crown of road. The lower coat to form a suitable resilient covering to protect the foundation from undue vibration caused by heavy traffic. The upper or wearing surface to constitute a voidless carpet of granite and other suitable aggregate cemented together with a pure bitumen soluble in carbon bisulphide to the extent of 99·9 per cent.

Material for lower coat to consist of an aggregate of Guernsey or other approved granite,[2] mixed and coated with a percentage of suitably fluxed natural asphalt. The exact proportion of mineral matter and soluble bitumen contained in the refined asphalt to be used to be ascertained by analysis. The percentage of aggregate to be added is to be determined by the percentage of mineral matter contained in the natural asphalt, and the proportion of pure bitumen to the aggregate not to be less than 7½ per cent. The aggregate to be added to range from 1-in. mesh downwards to ⅜-in. mesh.[3]

Material for upper coat to consist of Guernsey or other approved granite chippings or crushed quartz, graded so as to

[1] It was found shortly after the work was commenced that this method was not satisfactory, the portion of the work so executed had to be broken up, and the whole area spread with hand floats and allowed to set without any rolling.

[2] The surplus old macadam not required to shape the road was sifted and broken to proper size and was used to assist in forming this aggregate.

[3] This was found to be too large and ½-in. to ⅜-in. granite was used.

pass through $\frac{1}{4}$-in. mesh, but free from dust, a percentage of refined fluxed natural asphalt to be added containing approximately 10 per cent. of pure bitumen soluble in carbon bisulphide.

The mineral material contained in the fluxed bitumen used to be ascertained by analysis, and silicious grit to be added in very definite proportions which were set out in considerable detail.

There were other clauses in the specification, which need not be included in this description, of a method of road construction which appears to have introduced some novelties. It is specially interesting to observe, in the footnote on the preceding page, that rolling had to be discontinued, as the portions of the carriage way, so treated, broke up almost immediately after construction, and that hand floating was substituted with satisfactory results. This experience is not an isolated case, as there is at present a growing disposition to abandon rolling and to substitute hand floating in some special forms of road construction.

This road was fairly successful, and the engineer who was responsible for the work stated that the laying of this material entirely by hand, and eliminating all rolling, had the effect of reducing surface corrugations or waves to a minimum. This is interesting, as one of the reasons for a wavy road has been that it is first "set up" by the initial rolling, and having been once started, the waves are increased by the subsequent traffic.

Lithomac.—The trade name of a material which is composed of crushed granite, whinstone, or other hard stone of uniform size [about $\frac{1}{2}$-in.], sharp silica sand, pure limestone powder, and specially refined "natural elastic bitumen" in certain proportions; when the stone and silica sand, etc., have been dried and heated to about 250° to 275° F. they are mixed in a special machine with the bitumen melted in a special tank to a temperature of 300° to 325° F. While still hot the mixture is spread evenly over the foundation [direct on the original road if good] with iron rakes, and then rolled to about 2 ins. thick with a 5-ton roller, and then, whilst surface is still warm, a "skim coat of pure refined natural elastic bitumen" is poured over the surface whilst at a temperature of 300° F., and evenly spread with rubber squeegees. On this a top dressing of fine clean, dry stone chippings or coarse silica sand [free from dust] is spread and thoroughly rolled in, thus sealing the surface.

There are other methods of laying this material which have proved quite successful for medium traffic.

Cormastik.—This is a trade name given to a bituminous road surfacing compound which was laid on one of the lengths of the Sidcup trials and which was described as follows:—

"'Cormastik' is composed of $\frac{1}{4}$-in. to $\frac{3}{8}$-in. granite or basalt chippings; sharp Thames sand; powdered Sicilian rock asphalt containing about 10 per cent. of pure bitumen; Portland cement.

"The binder employed is Cuban natural asphalt refined and suitably fluxed, and for which is claimed:—

"(1) It has extremely high softening and melting-points, viz. 250° and 280° F. respectively.

"(2) Ability to withstand disintegrating effects of water.

"(3) Ability to resist extremes of temperature.

"(4) It has a very rubbery nature.

"The existing firmly compacted surface of the macadam road is vigorously swept, and painted with a bituminous solution. The aggregate is then spread in a heated condition, minimum thickness $\frac{3}{4}$ in. The material flows freely when taken from the boilers or cauldrons and applied to the road. Ordinary wooden floats are used for levelling, and finally the material is rolled to a smooth surface by a tandem asphalt roller weighing about 3 tons. The 'Cormastik' is thus consolidated and forced into the interstices of the road surface upon which it is laid and to which it strongly adheres. The material sets rapidly so that traffic can be allowed over the surface within an hour after completion.

"By rolling with a 3-ton roller. It is probable that further consolidation under traffic during the first three months does not exceed $\frac{1}{16}$ of an inch.

"It is claimed that this material provides a non-slippery foothold for horses. Its life under heavy mixed traffic conditions is stated to be not less than three years and up to fourteen years under light traffic conditions. It is claimed that it is unaffected by any climatic conditions owing to the use of Cuban natural asphalt as the binder.

"It is claimed that the material can be laid at any season of the year provided the roadway upon which it is laid is dry and that no rain has fallen for at least two days.

"The price varies according to locality, but the contractors are prepared to apply the material upon considerable areas within a twenty mile radius from Charing Cross, London, at 2s. per yard super, and to enter into maintenance contracts for varying periods, according to the nature of the traffic carried. The material can be supplied to purchasers who prefer to carry out the work of laying themselves. The material is also supplied in the form of bricks 9 ins. by 4½ ins. by 2 ins. thick to be laid on concrete foundations for heavy street traffic in towns and cities.

"It is claimed:—

"(1) A strong point in favour of the use of this material is the small thickness necessary to be laid on sound foundations.

"(2) Scarification is avoided.

"(3) Shortness of time occupied in laying.

"(4) Inexpensive initial cost, and cost of maintenance.

"(5) Shortness of time occupied in carrying out repairs.

"(6) Silence under mixed traffic conditions."

The report on this material, in 1912, was that it had to undergo extensive repairs, in 1914 not much of the original surface was left, and it had a very patchwork appearance owing to the repairs which had been carried out, and in 1915, that it was in poor condition and required reconstruction.

The failure was in some measure attributed to overheating of the matrix, the difficulties encountered in laying it, owing to the traffic, and some instability of the foundation. It was also laid on a "scarified" surface whereas it will be observed above that the material could be laid direct on the road surface if thoroughly dry and that scarifying was unnecessary.

Ferromac.—The author will next deal with "Ferromac," although it does not come strictly within the purview of

"Bituminous Roads". At one time this material was brought very prominently forward and caused a good deal of attention and some criticism.

So far as the author ascertained at the time, "Ferromac" consisted of magnesian limestone, Portland cement, and ferro-oxide. These were thoroughly mixed and incorporated together. This, of course, was a dry "cementitious" powder, which was then mixed with stone chippings, about 1-in. gauge in the proportion of about 4 of chippings to 1 of the powder. This mixture was then spread on the road requiring re-surfacing, to a thickness of about ¾ in. On this was then spread ordinary macadam of suitable gauge. This was then dry rolled. The whole surface was then "watered" by an ordinary water-cart, containing about 40 lbs. of a chemical [presumed to be silicate of soda], to 60 gallons of water, and again rolled, "until the binder is seen working up between the stones, but not actually over-running the surface". A further layer of chippings, ¼ in. to dust and "Ferromac" powder mixed as before, was laid about ¼ in. thick over the surface, a further "watering" took place, then a little more powder, and when nearly dry the surface was dusted over with sand or pine stone dust and the road was finished.

Experience showed that such a road was apt to get dusty and was improved by being tar painted. The nature of this description of road appears to be that of a rather weak concrete.

Robeson Process.—Another process was that known as the "Robeson Process," of which "Glutrin," composition not given, was used. A short description in the author's possession is as follows:—

"Glutrin," a proprietary article, is used in this process. The road is scarified if necessary and reformed to the proper contour, then re-rolled firm without water. Upon this surface a 1 in. bed of chippings of a gauge of ½-in. to dust mixed with a powder [composition not given] is laid; upon this a new coat of metal is laid and rolled until it has properly keyed. All the work to this stage must be dry. Then the road is watered with a solution of "Glutrin" and water until a satisfactory surface has been formed. As a dust palliative it is applied as a solution of "Glutrin" with water.

There does not appear to be much binding property in the above process, and the author is not aware that this method ever went much further than the experimental stage.

The following was a German process, but it does not appear to be very "promising" and is somewhat meagre in detail:—

Nassau Pykoten Process.—Pykoten is a dry powder composed of a special mixture of volcanic ash, caustic lime, and slack lime or calcium hydrate. This powder is mixed dry, i.e. before tarring with the aggregate composed of broken stones, chips, screenings, and sand. The proportions are 12 kg. to every 100 kg. of pitch oil, and this is thoroughly mixed together in proper machines. The road crust is built up in two layers, the bottom layer before rolling is evenly covered with pykoten which is rolled into it.

The following is a Belgian process, but which, like many others, did not meet with much success; it is called the—

Rhouben Process.—This system consists in the admixture, when cold, of a powder, said to consist of tar, in order to form a concrete, and it is stated that the presence of this "tar powder" gives an elasticity and resilience which is not found in an ordinary concrete road. It is claimed for this process that no dust can be formed and that the surface is sealed. A description of this method, as laid in France, in 1912, says that the "concrete" consisted of the following proportions: 825 lbs. of slow-setting cement, 1,300 lbs. of Rhine sand, 2,860 lbs. of ballast chippings or "macadam," and 220 lbs. of "Rhouben," the whole mixed with about 5 gallons of water per cubic yard. This was spread on a proper foundation, and consolidated by rolling to a thickness of about 4 ins. This rolling was done by a 5-ton roller until the "mortar" overflowed the surface when it was floated by hand with a "set board". The cost appears to have been about 4s. 6d. per square yard.

A similar trial in Brussels consisted of 765 lbs. of Portland cement, 1,100 lbs. of porphyry dust, 3,300 lbs. of broken road stone, 440 lbs. of "Rhouben". How the powdered tar or "Rhouben" is manufactured is not stated, but it is believed to be a trade secret.

German Process.—At the town of Chemnitz, in Germany, the following method was adopted, but was not altogether successful, as might have been foreseen:—

Ordinary macadam heated and dipped into hot tar from 70° to 80° C., the tar being contained in boxes with perforated bottoms. This was laid 17 cm. in depth and rolled "until soft elastic places show themselves," then "dry gravel" was applied and rolled till dry. The road was kept closed to traffic for four days! it was then tarred and covered with fine gravel and opened the next day to the traffic.

Another German method was known as "Kaiserlanten"! The description of it is as follows:—

Macadam up to 7-cm. gauge laid on "existing road bed". Then sand mixed with reinforced concrete ["a mixture of 1 part per cent. to 2 parts of pure sand and 4 parts of iron pairings, i.e. chips or 'filings'"] mixed with water is run in and rolled with a 10-ton steam roller. On this is laid 5 cm. layer of tarred surfacing material containing stones up to 5 cm., then rolled and tarred, gravel of 5 cm. grain being added.

The tar macadam is made by "stone thrown into a furnace heated nearly red-hot and then shot into an iron trough filled with coal tar erected in front of the furnace". The stone then removed with forks and put on the road. Road opened for traffic two or three days after completion.

I am not aware whether this method with its high-sounding title was any more successful than its namesake who certainly did not make a road to victory!

Aeberli System.—A Mr. Aeberli, of Zurich, introduced this system which is said to answer very well. Dry and well-heated road metal is impregnated with coal tar at 35° to 40° C., which is shot into heaps and well covered with sand, remaining so for about three weeks during which time a "soft pitch" is formed. Then this stone is laid 8 to 14 cm. thick and well rolled into the bottoming and exposed to air and sun for three days. This forms hard pitch. He then rolls on this bed a layer of spalls 3 to 5 cm. treated in a similar manner. The only novelty in this system appears to be that of covering the tarred macadam for three days, but he claims that this forms the soft pitch and when exposed it becomes hard.

This is also said to have been laid in Milan, in 1910, and in other parts of Italy.

Tarbetonite Process.—In this system "road metal" was mixed with refined coal tar at a temperature of 60° to 80° C., and "a portion" of it was put down at once and the road was then covered with Toepel's special filling or binding preparation, the particulars of which have not been disclosed. The material is spread over the new surface in sufficient quantities to fill all interstices and to leave a thin layer after the material has been well worked into the holes with brooms. "The preparation absorbs the tar and sets like concrete. After a few days the stuff is swept off and the joints laid bare. The road is then surface tarred with tar of a temperature of 60° to 80° C., receives a thin top dressing of chips, is covered again with the stuff that had been swept off and rolled once more. This finishes the first stage of the work. After three or four days the stuff is again swept off and the road receives another coat of tar and a top dressing of grit or sand 5 mm. thick."

The Ohl Process.—This is another German method which was introduced a few years ago with some success. The aggregate employed was as follows:—

1 cub. m. of small broken stone	size	2 to 3 cm.
0·66 cub. m. of large chips	„	1·5 to 2 cm.
0·36 „ „ screenings	„	5 to 10 mm.
0·16 „ „ sand	„	2 „ 3 mm.

The aggregate is thoroughly mixed in an Ohl mixer with a hot composition consisting of 60 to 70 per cent. of pitch and 40 to 50 per cent. of anthracene oil.

The whole mixed mass is spread and levelled in a *single layer* 13 cm. deep and consolidated with a 15-ton roller. The rolled layer is topped with a coat of screenings 15 to 20 mm.

thick, rolled and tarred. The quantity of the tar composition used is 11·2 kg. per sq. m. of road and 62·9 kg. per cub. m. of aggregate.

The chief feature in the process is that fine sand is added to the small broken stones before these are mixed with tar in proportion of 1 part of sand to 4 parts of road metal. The object of the sand is to stop the movement of the tarred stones under the road roller, the absence of this precaution being no doubt the cause why in the Aeberli process the road cover is not consolidated into a compact mass.

The small broken stones of 4·5 to 5 cm. mixed with fine sand are heated in a revolving drum and freed from dust and then saturated with a composition consisting of hot pitch [60 to 70 per cent.] and anthracene oil [40 to 50 per cent.]. With the same composition are saturated, each kind separately, large chips 15 to 30 mm. and screenings 5 to 15 mm. in size.

The material is put down in two layers, as described below, because it was found in many cases that if the material is put down in a single thick layer it is not sufficiently consolidated by the rolling, because the stones move about under the 12 to 15-ton rollers, which is the usual weight of rollers employed in Germany.

First of all a thin layer of tarred chips is spread over the foundation and rolled. Upon this follows the first layer of graduated road metal which in its turn is also covered with a thin coating of chips and lightly rolled. The bottom layer thus finished is then covered with a thin coating of tarred screenings and the whole well rolled and consolidated. The second layer is then spread and treated in a similar manner with a top dressing of chips and screenings until a total thickness of tar macadam 12 to 13 cm. is formed.

Kiton Process.—This process was invented by Dr. Raschig of Ludwigshafen on the Rhine. In his German pamphlet on "The Construction of Dustfree Roads according to the Kiton Process" [1911], the author states that Kiton, which is applied in its wet state, has the property that after it has once become dry, it will not absorb water and is not affected by same. The tar is made impervious and insoluble by the admixture of clay. Kiton consists of 60 per cent. of tar, 10 per cent. of clay, and 30 per cent. of water. It is easily dissolved in water with which it forms a black fluid of the consistency of milk and settles down in the water as a fine soft powder, but only after considerable time.

It is doubtful if this process had any success as clay cannot be a good material to use in road construction.

Westrumite Process.—It is claimed for this method that "Westrumite asphalt" is an asphalt emulsion, combined with various resinous and ammoniacal chemical substances. The following is a description of this process as carried out in France, in 1910, on a trial length of about 120 lineal yards in length:—

"The road crust rests on a foundation of 0·18 m. thickness of concrete [7 ins.] consisting of 5 parts of porphyry ballast, 5 to 25-mm. gauge [$\frac{3}{16}$ to 1 in.], 3 parts of sand, and 2 parts of Portland cement. On the upper surface of the concrete, pieces of stones or slate refuse have been stuck in to form anchorage between the road crust and the foundation.

"The road crust is composed of a mixture of the type called 'ballast' of porphyry and limestone, as well as dust and powdered lime in the following proportions:—

50	kg.	'ballast' of porphyry.
50	,,	,, of limestone.
75	,,	dust of limestone 0·10.
25	,,	powdered lime.

"The whole is properly mixed in a mixer worked by a motor, with the addition of a sufficient quantity of Westrumite asphalt, so as to impregnate the whole mass in the proportion of about 15 kg. [33 lbs.] to 200 kg. [440 lbs.] of the mixture, as given above.

"The Westrumite asphalt is used pure without the addition of water. The composition given above is capable of modifications according to local conditions.

"Coming out of the mixer, the mixture is spread uniformly over the foundation to a depth of about 8 cm. [about 3 ins.].

Two or three hours after the spreading, the road crust is rolled by means of a roller of 5 to 6 tons until no further compression is noticed; the thickness is thus reduced to about 6 cm. [2¼ ins.].

"Then a light layer of Westrumite asphalt, dissolved in water, is spread over the road crust, and is mixed with powdered lime, which is brushed into the voids with piazzava brooms.

"The work is finished off with a light layer of sand or limestone dust. Some days are necessary to allow the road to dry before it is opened up to traffic."

Many of the above descriptions of road making are merely given as a matter of record and history, but they serve to show how keenly alive road makers and others have been to the necessity for action after the stagnation which has prevailed in this subject since the days of Telford.

Rocmac.—Before leaving the subject of various miscellaneous methods of road construction which the author has included in this chapter, it will be well to give a few particulars of "Rocmac," which at one time was used as a method of road construction.

A trial length was laid, in 1911, in the famous Sidcup trials, which was then described as follows by the proprietors:—

"The material is Hornfels or Elvan from Penlee. The gauge to be from 2¼ ins. down to 2 ins.

"The binder is a silicate-saccharate-carbonate, the foundation of which is silicate of soda, sugar, and carbonate of lime. The sugar is not used for adhesive purposes, but to assist the chemical action of the silicate on the carbonate, and secondly, to assist the resistance of the matrix to frost. This binder will resist great differences of temperature. It has been laid in Canada with the thermometer below zero and again fires have been lighted on the road immediately after it has been laid, and in neither case was the road affected except that in the latter case setting was somewhat accelerated in the immediate neighbourhood of the fires. It is also waterproof throughout the whole depth of the coat.

"It is claimed that the durability imparted by this binder to a road is about three times that of a water-bound macadam road laid with the same road stone.

"A matrix is formed of the mixture, as in making concrete, of Rocmac solution with limestone containing not less than 93 per cent. of carbonate of lime. The limestone must be crushed to ¼-in. gauge and dust, 60 per cent. being fine dust. This matrix is applied cold and laid on the original surface to a thickness of 1 in., in order to supply binder for a complete coat of 3 ins. The road stone is then spread on the matrix and rolled in.

"The Rocmac solution is sent ready for use in casks. The limestone comes direct in trucks from the quarry and requires no protection. No special machinery is required. Ordinary tools used in making a water-bound road need only be supplemented by a gauge box for measuring the limestone, a bucket for measuring the Rocmac solution, and a mixing board.

"The consolidation is partly by rolling and partly by chemical action. As it is a slow-setting binder and as the chemical action appears to repeat itself at certain temperatures and with a certain humidity of the atmosphere, it is probable that traffic helps in the consolidation and also to wear away any superfluous binder which may come up to the surface.

"The foothold for horses is the same as that for a water-bound macadam road, except that as Rocmac is impervious and immovable it affords a foothold in all cases at least as good as that of a macadam road in good condition. The expected life is about three times that of an ordinary macadam road. As stated above there is no likelihood of it being affected by frost, and in all other respects, except that of durability, its qualities are the same as an ordinary macadam road. It will resist any sun temperature without softening. It can be laid in any weather, during frost, sun, wet, or heat, but it costs rather less to lay it in wet weather. There is no danger to cattle, herbage, or fisheries from the use of Rocmac."

It appeared to stand well for about a year and then began to wear unevenly; it was surface dressed with tar, but in 1914 it was "practically worn out". It underwent considerable repairs with tarred macadam, and in 1915 the surface showed very few signs of the original Rocmac.

Natural Rock Asphalt Macadam.—Before passing on to the question of the use of furnace slag as a substitute for stone in the construction of a bituminous road, it will be well to say a few words on the use of natural rock asphalt as a binder, and also broken up in the same manner as stone is used in the formation of a water-bound macadam road.

The Sidcup Trials.—In the above-mentioned Sidcup trials a length was tried of "natural rock asphalt, broken into rectangular pieces, laid without the addition of any other materials whatever. The ground is excavated to a depth of about 4½ ins., the bottom made solid, and the asphalt macadam spread over the surface about 6 ins. thick and well rolled. It is absolutely necessary to have warm, fine weather while the work is in progress."

Failure of Trial.—This trial was doomed to failure; such a material used in this manner without any binding would require an enormous amount of rolling even if the "beds" had been thinner, but to attempt to consolidate such an elastic material, laid to such a depth as 6 ins., was courting disaster. The road never became properly consolidated, and it had to be removed and another form of construction put in its place within a few months of its being laid.

Other Trials.—The author understands that this method has been tried in Egypt with some success, and he has seen a road in Worthing constructed in this manner which was fairly successful, but it is evident that in order to secure success, a very lengthy period of heavy rolling must be done in order to consolidate such a material. It is, of course, very different where the asphalt rock is previously pulverised into small particles and well heated before being laid as a "compressed asphalt roadway," but even then it requires very severe ramming to make it thoroughly consolidate.

American Trial.—As a binder, however, when thus pulverised, it would act differently and the author understands that such a road has been successfully made in America in the following manner :—

The asphalt rock was pulverised into a "powder or fine sand". The road on which it was tried was a gravel road, "about 8 ins. deep consolidated"; this was removed and the "sub-grade" contoured and rolled. Then a course 4 ins. in thickness of limestone, broken to 1-in. to 1½-in. gauge, was spread and *once* rolled. The asphalt powder was then spread on this to a depth of 1½ ins., taking care to rake it into the interstices of the metal underneath, but without disturbing it. As it was levelled over, a roller [weight not given] was worked on it, "in the same manner as for ordinary macadam".

The result was quite satisfactory except that in cold weather the asphalt had a tendency "to work into lumps," but spread itself out again in warm weather when the temperature rose to above 70° F. This was a novelty, but the author is not aware whether the experiment was sufficiently successful to warrant a continuance of the practice. If some such binder had been applied in the case of the Sidcup trial, and the thickness of the bed of broken asphalt reduced before rolling, it is a matter for speculation as to whether this trial might not have been better than it proved to be.

Rubber Roads.—One other method may be referred to before passing on to the question of slag, and that is, as to whether rubber can be used as a material for road surfacing. Many efforts have been made from time to time to construct roads of natural rubber, notably in the borough of Southwark, where experiments were conducted between the years 1912 and 1915. The early trials were by dovetailing a "pad" of rubber on to wood blocks, but the dovetailing worked loose and the trial was not very successful. Another trial is about to be made by the Rubber Growers' Association by vulcanising rubber about ⅜ of an in. thick on a steel plate 9 ins. long by 3 ins. wide, with projecting lugs underneath which will be imbedded and secured in concrete made with a fine aggregate. It appears that there is always a considerable quantity of surplus rubber which is unsaleable and if these blocks are found to be successful and can be put on the market at a reasonable cost, they should make an excellent road surface. A material like rubber should be absolutely impervious, non-slippery, easily cleansed, and ideal as a surface for vehicles as being so resilient and quite noiseless. It would not be possible to lay the rubber in sheets, for obvious reasons, on a public street, consequently the method adopted at the entrance to Euston Station, where large sheets of rubber are fastened down on each side, cannot be adopted. It is to be hoped that the experiments at Southwark will ultimately prove successful.

Furnace Slag.—Only a few words are necessary with regard to the use of slag as a material for use in road making, as the process for the manufacture of ordinary tarred slag is very similar to that which is employed in the case of the bituminous roads already described.

Formerly, untreated slag was largely used, in neighbourhoods where it was plentiful and cheap, not only for the foundations or sub-grades but also for the surfaces of roads where it was laid and consolidated in the same manner as ordinary water-bound macadam. Needless to say that such roads were not satisfactory, they were dusty in dry weather, and manufactured a black sticky mud in wet weather.

But at the advent of bituminous-bound roads, this material was found to be an excellent substitute for stone in the construction of "tar macadam" and is now largely used in this manner. Tarred slag must not be confounded with Tarmac, with which material the author will presently deal.

Selection of Slag.—It is necessary that considerable care should be exercised in the selection of the proper slag for road purposes before it is "treated," as owing to the complex chemical and other actions which take place in the furnaces from which this material comes, the composition of slag varies considerably in texture and chemical character.

Furnace slag is generally found to contain: silica, alumina, lime, magnesia, ferric oxide, and sulphur, as well as other matters, in very varying proportions. Consequently some slags are quite unfit for road purposes. Mr. J. Walker Smith, M.Inst.C.E., in his excellent book on roads,[1] says:—

"For road-making purposes it is considered that slags which contain about 40 per cent. silica, 40 per cent. lime, 20 per cent. alumina, are about the best. Those which contain more than 45 per cent. lime, or less than 14 per cent. alumina, or under 33 per cent. silica are usually weak and apt to disintegrate by exposure to air or water. Magnesia in moderate quantities is favourable to the resisting power of slag. Those which are too silicious are glassy, they crack and have a tendency to fly to pieces on cooling."

It is no doubt essential that the selected slag should not be of a friable or brittle nature, nor should it be too porous, but be as dense and hard as possible, and of tough and even texture.

It is stated that slag should weigh not less than 23 cwts. per cubic yard, and should contain not more than 10 per cent. of what may be called a "honeycomb" appearance. The preparation of ordinary tarred slag is much the same as that employed for the treatment of stone in the case of tar macadam, and should be carried out in machines specially adapted for the purpose, and the tar, or bituminous compound with which it is treated, should be specially prepared and selected and be properly applied, in order to secure success with this material.

Method of Laying Tarred Slag.—The author, through the courtesy of a firm of well-known contractors for this class of work, is able to give the following description of the manner in which this material should be laid on a road:—

"The surface of the roadway or other area proposed to be paved shall [in the case of an existing road or old foundation] be scarified by steam scarifier, or picked over by hand labour and levelled, to leave a camber or fall of the cross section of $\frac{1}{2}$ in. to $\frac{5}{8}$ in. to 1 foot, care being taken to excavate all soft and weak places, which should be taken out at least 1 foot in

[1] "Dustless Roads Tar Macadam; a Practical Treatise for Engineers, Surveyors, and Others." [Charles Griffin & Co., Ltd.]

depth and filled in with good dry hardcore. The whole surface should then be moderately steam rolled to ensure thorough consolidation [which is a very essential point], but the rolling should be discontinued before the surface becomes 'smooth,' as a 'key' is necessary, and an air circulation is required in the foundation.

"The tar slag macadam is then laid on the foundation prepared as above in two coats of varying thicknesses according to the traffic or purposes for which it is required, each coat being well rolled with steam roller, weighing not more than 6 tons, and the surface on completion being dusted over with fine chippings and finally well rolled until it is quite hard. The material of the 'bottom' coat should be spread with shovels in the same way as ordinary macadam, and should be allowed to lay open, before being rolled, for at least twenty-four hours to allow it to become partially set and 'tough,' which ensures the levels remaining true; and the 'top' coat laid with rakes [kept heated] to enable a level and true surface to be obtained. This coat should also remain open a few hours before rolling, and where possible, the rolling of the material should not be done during rain or until it has had sufficient time to dry.

"The thickness at which the material should be laid may be taken generally as shown below.

"Roadways [with local or through traffic as for Urban and Borough Council roads and similar purposes].

"Work to be laid in two coats, totalling 4½ ins. in thickness.

Bottom coat		3	ins. thick of	2-in.	gauge	material.	
Top	„	1½	„ „	1¼ „	„	„	

"Roadways [with light traffic], cul-de-sacs, yards, etc.

"Work to be laid in two coats, totalling 3½ ins. in thickness.

Bottom coat		2½	ins. thick of	2-in.	gauge	material.	
Top	„	1	in. „	¾ „	„	„	"

The Sidcup Trials.—In the Sidcup trials, two lengths of tarred slag were laid, the following being the original description by the contractors who laid them :—

"The material is blast furnace slag ranging from 2¼ ins.

down to ¾ in. When laid in one coat of mixed gauges the proportions are about 60 per cent. ranging from 2¼ ins. down to 1¼ ins., 30 per cent. from 1¼ ins. down to ¾ in., 10 per cent. from ¾ in. down to ½ in.

"The binder used is distilled tar without any admixture or other material, and after setting is not affected by normal changes of temperature."

The behaviour of these sections was very fair considering the traffic and other conditions.

Another description of a slag road may be given as it was laid in three coats. The bottom or strength crust was composed of untreated slag 2½-in. to 2-in. gauge rolled and consolidated [1 ton to about 12 square yards]. This was grouted with a hot bituminous mixture composed of 33½ per cent. tar to 66⅔ per cent. pitch, and 50 per cent. by weight of sand. Dry chippings then spread over the surface and rolled, leaving the interstices unfilled. The binding coat consisted of 5 parts 1½-in. slag, 4 parts ⅜-in. slag, 2 parts sand, all mixed in a machine with 7 per cent. of tar and pitch in equal proportions, and laid on the strength coat at a temperature of about 150° F. and rolled immediately [1 ton to about 9 square yards]. The wearing coat was composed of 5 parts ½-in. slag to 2 parts of sand mixed with 8 per cent. of tar, laid at a temperature of about 100° F. and well rolled [1 ton to about 42 square yards]. This was also fairly successful.

Tarmac.—To Mr. E. Purnell Hooley, M.Inst.C.E., we are indebted for this excellent road material which he introduced, about sixteen years ago, on the roads in Nottinghamshire, when he was surveyor to that county. "Tarmac is the trade name of a material composed of selected furnace slag, thoroughly indurated and impregnated with tar and other bituminous compounds, which is effected by mixing slag taken direct from the furnaces, allowing it to cool to a certain fixed temperature, and then impregnating it with the tar compound at the same temperature. The large blocks of slag are previously broken into suitable sizes for road metal, generally ranging between ¼-in. gauge to 2½ ins., but the slag retains its heat whilst being broken and is at the desired temperature when the 'mixing' takes place. The heat reaches to the very centre of each piece of the broken slag without in any way affecting the surface, which is difficult of achievement with granite or other natural rocks or stones. Every particle of moisture must also have been eliminated by the intense heat to which the slag had been subjected in the furnace.

"The material thus treated is ready for removal to any part of the country directly it has been made, and is now very extensively used in all parts of Great Britain."

Merits of Tarmac.—Mr. Hooley found that this description of road construction withstood the ever-increasing traffic on the roads of Nottinghamshire better than any other material, and it is claimed that not only does this material maintain its sealed face for some time after being laid, but that the traffic tends to consolidate and compress it more and more for a considerable time after it has been laid, and that as it is slightly resilient and very smooth it is an ideal surface for all classes of self-propelled traffic. It is also claimed for it that from the very first it presents a waterproof and perfectly sealed surface against any infiltration of water.

Instructions for Laying Tarmac. — Mr. Hooley was naturally anxious that this material should be properly laid on the roads, for it is evident that, however excellent a material may be for road making, it may be impaired or spoilt by careless or improper application. He, therefore, in 1909, issued certain "Instructions for Coating a Road with Tarmac," and followed this up in 1913 with further instructions on the same subject.

The following extracts from the 1909 "Instructions" will be of interest :—

(1) The camber must be 1 in 48.

(2) "All holes, depressions, or soft places on the road must first be taken out and made good in ordinary ballast or rammed as may be most suitable. The surface of the road

should then be carefully swept to remove any dirt, dust, or loose material."

(3) Then a thin surfacing of $\frac{5}{8}$-in. Tarmac, "less than 1 in. thick," to be laid as a base for the coarser material, all traffic to be kept clear of this fine material.

(4) Before this base has had time to dry the $2\frac{1}{4}$-in. Tarmac should be laid as close as possible, so that every piece of material touches its neighbour, and a steam roller should be passed backwards and forwards over the same from the sides towards the centre; about four journeys each way should be sufficient. Then "a small quantity of the $\frac{5}{8}$-in. material should be carefully swept into each hole so as to fill up the spaces". This is left without any rolling and the $1\frac{1}{2}$-in. material is spread, and then rolled, taking care to fill up with the $\frac{5}{8}$-in. material as before. "A dapping motion of the brush will best fill up these holes and every care should be taken to avoid converting the $\frac{5}{8}$-in. into a layer."

"It should be most distinctly understood that this $\frac{5}{8}$-in. material should only be used as a filler to the $2\frac{1}{4}$-in. and $1\frac{1}{2}$-in. after the bottom layer as before described."

(5) Finishing with a feather edge is described as "fatal". Tarmac should be finished in a straight or butt joint.

(6) Instructions are given as to the best method of carrying out the work when only one half-width of road can be done at a time.

(7) Each 7 yards of finished Tarmac road should contain as nearly as possible 1 ton.

(8) Each 100 tons of material if laid by this system should contain[1] :—

10 tons of	$\frac{5}{8}$ in.	
40	,,	$1\frac{1}{2}$,,
50	,,	$2\frac{1}{4}$,,

(9) Instructions are given as to the procedure to be adopted in cases where it is not intended to coat the whole width of the carriage way with Tarmac, e.g. that two grooves

[1] These proportions were slightly altered in the Instructions issued in 1913, as will be seen on comparing them.

should be cut in the old surface on each side of the proposed Tarmac treatment, "at least $2\frac{1}{2}$ ins. on the outer side and $1\frac{1}{2}$ ins. on the inner, 6 ins. apart on either side of the road. These grooves should be carefully brushed free from any loose material, and when ready exactly the same procedure should be followed for coating the whole road surface."

Mr. Hooley's instructions, which he issued in 1913, were "Instructions to Workmen," and contained, *inter alia*, the following:—

Interference with Traffic.—The undesirability of occupying the whole area of the road for repairs is pointed out, and that space should be allowed for passing vehicles. That no loose materials should be left at night, but every day's work must be completed, "to give a free and uninterrupted passage over the new face". In case of any impossibility to finish, "every precaution must be taken to make everything safe by covering loose material up". Both ends of the unrolled surface to be lighted and a watchman left in charge.

Finishing Ends of Coatings or Patches.—All ends must be left at an angle of at least 120 so as to avoid unevenness of surface. These feather edges to be removed when continuing the work, and a butt joint made. "On no account must Tarmac be used for sloping or feathering; it is unsuitable for such work, and material so used would be wasted." A straight butt joint must only be used with Tarmac.

Tipping Tarmac.—Tarmac should not be tipped on the grass side but should be applied at once to the surface. A "last load" should remain full all night if arriving too late to be put on the surface.

Other directions follow which are dealt with in the former Instructions, but the following are either additions or modifications:—

Slag Dust.—On completion of the laying of the Tarmac on the road and the final rolling, "a dressing of fine dry slag dust shall be swept over the surface. After the first rain has soaked the slag dust the workmen shall immediately sweep the whole road from the centre to the sides to remove any surplus dust."

The proportions of the material used are also altered to the following for each 100 tons:—

3	tons of	$\frac{3}{8}$	in.	dry slag.
12	,,	$\frac{5}{8}$	,,	Tarmac.
40	,,	$1\frac{1}{2}$	,,	,,
45	,,	$2\frac{1}{4}$	,,	,,

It is presumed that the $\frac{3}{8}$-in. dry slag refers to the slag dust mentioned in the preceding paragraph.

The "feathering" is also mentioned as being done in *dry* material, but that feathering of all kinds should be avoided if possible.

These instructions are thoroughly practical and useful, and some of them are applicable to other methods of road construction as well as Tarmac.

Sidcup Trials.—In the report on the "Sidcup Trials" it is stated that the aggregate of Tarmac consists of selected blast furnace slag produced from various blast furnaces, and is run in a molten state from these furnaces into suitable receptacles, in which it is shunted to the company's premises adjacent to the furnaces and there allowed to remain until, in the process of cooling, it has solidified. It is then tipped on the slag selecting ground in blocks of about 5 tons each, broken by hand into pieces of suitable size, and then crushed, graded, and treated with the company's tar composition, consisting of refined or distilled tar, pitch, and other ingredients. The works possess a complete tar distillation plant, and the mixture is prepared to certain uniform, chemical, and physical standards, which are known to give the best results as regards binding strength, durability, and resistance to atmospheric changes.

The description of laying this material has already been given, and the trial length at Sidcup was laid in that manner, in 1911. The report of the condition of this length in 1915 was to the effect that the surface was fairly good, but that small defects and signs of wear were apparent on one part of the section.

It was stated in 1914 that it was in very good condition, and, with one other of the twenty-three trial sections put down in 1911, was certainly the best of the proprietary articles originally laid.

It was neither slippery nor dusty, and had received no repairs, nothing having been necessary except surface "dressing" with tar in 1913 and 1914. The traffic on the road was over 3,000 tons per twenty-four hours.

Wandsworth Trials.—In the Wandsworth trials, to which reference has already been made, Tarmac was laid on an area of nearly 2,000 square yards, and was spread in three layers, the bottom or strength crust graded from 2½-in. to 1½-in. gauge, the second or binding course, with 1½-in. to ½-in., and the third or wearing coat, with ⅜-in. chippings, the surface being afterwards finished by spreading dry slag dust. This was laid in 1911, and was subjected to a traffic of nearly 5,700 tons per twenty-four hours. The report, in 1915, on its condition was that it was quite good, with a good surface and a good super-elevation, and was certainly the best of the five trial sections.

Tarmac in Nottinghamshire.—The following report on the Tarmac laid in Nottinghamshire, is also of considerable interest:—

From a paper read at a district meeting of the Institution of Municipal and County Engineers at Nottingham, early in 1919, by Mr. Haller, the County Surveyor, it appears that in 1914, 85 miles of rural main roads had been already surfaced with Tarmac, and by the end of 1918, 90 more miles of rural main roads and 24 miles of urban main roads had been similarly treated, a total length of nearly 200 miles. As a rule, the re-surfacing of these roads was done with Tarmac for a width of 10 ft., laid in two coats, consolidated to a finished thickness of 3½ ins. The margins or verges on each side of these strips of Tarmac were 4 ft. in width, consolidated with water-bound granite, macadam, or slag. Naturally, disturbance took place along the edges of the Tarmac, which was partially stopped by carrying the bottom layer of the Tarmac 6 ins. wider than the 10 ft. on each side, and the untarred slag or granite macadam was rolled well down into it, thus making a sort of over-lap joint.

In the County of Nottinghamshire it is evident that, being a "horsey" county, it was necessary to leave these margins on each side of the Tarmac, but no more severe trial could possibly be given to a road than thus constructed. It has no lateral support, a matter of the *greatest* importance, and the margins or edges along each side might be subject to continual wearing and breaking off of the edges. It is a great "feather in the cap" of Tarmac that it seems to have stood these unreasonable tests in such an excellent manner.

Claims for Tarmac.—There is no doubt that this material has long since passed the experimental stage and has taken its place in road construction and maintenance. It is claimed for it that:—

(1) It can be laid by unskilled labour under the most ordinary "instructions".

(2) It arrives on the site quite ready to be laid without any addition to it or any "manipulation"; it can be spread with the ordinary road tools and is "fool-proof" against stupidity or "errors of judgment".

(3) That the surface is sealed from the very commencement and requires no "after" treatment.

(4) That it makes a resilient road suitable for all descriptions of traffic.

(5) That it is economical in first construction and in its subsequent maintenance.

(6) That it is non-slippery and dustless.

(7) That it is easily repaired after any disturbance.

The next chapter will deal with the important question of "Bituminous Carpets".

CHAPTER VI.

BITUMINOUS CARPETS.

THIS method of road surfacing has become one of the most important questions in connection with modern road construction.

What is a Carpet ?—There is some slight confusion between the American and English definition of what constitutes a carpet, as the American road engineers define a carpet as follows: "*Carpets* are bituminous surfaces of appreciable thickness generally formed on the top of a road or pavement by the application of one or more coats of bituminous material with gravel or stone chips added". This is really our definition of a tar painted or tar sprayed road, whereas they call a "carpet" a "sheet asphalt pavement," defined as follows:—

Sheet Asphalt Pavements are those having a wearing surface composed of sand of predetermined grading, fine material, and asphalt cement, incorporated together by mixing methods. This is a good description of a bituminous carpet and could be adopted to describe this form of thin "wearing surface".

Another definition is given in the final report of the "Special Committee on Materials for Road Construction," to the American Society of Civil Engineers, in January, 1918, which is as follows:—

"A sheet asphalt wearing course consisting of predetermined graded sand, filler, and asphalt cement should be laid to a compacted thickness of not less than 1½ ins., and not more than 2 ins., on a binder course of bituminous concrete consisting of broken stone, or broken stone and sand, mixed with asphalt cement, the binder course having a compacted thickness of not less than 1 in. nor more than 1½ ins."

Asphalt Cement.—Asphalt cement was defined and approved by the American Society of Civil Engineers, in 1915, as follows:—

"A fluxed or un-fluxed asphaltic material, especially prepared as to quality and consistency, suitable for direct use in the manufacture of asphaltic pavements and having a penetration of between 5 and 250."

This definition is not very clear and a well-known American road engineer, says:—

"The writing of a specification for asphalt cement requires thorough laboratory knowledge of the chemical and physical characteristics of asphalt and also practical experience in the use of the material."

This is a very wise remark, as so much depends upon the proper consistency of the "bitumen," as the author calls it, or of the "asphalt," as the Americans call it, as to the success or failure of all descriptions of bituminous road construction.

Definition of a Carpet.—On reviewing the above "definitions" the author considers that a short description of a "carpet" might be: "A thin coat of a very carefully graded mixture of sand, or pulverised stone, powdered mineral matter, and a special bitumen, mixed carefully together in prearranged proportions at a certain fixed temperature". Or very shortly described: "An artificial substance as nearly approaching natural rock asphalt as possible".

Importance of Carpets.—The importance of these carpets in the development of road surfacing or reconstruction cannot be over-stated. For moderately heavy and "mixed" traffic they are now beginning to be universally adopted and are reaching a high state of perfection, especially in America, where enormous plants have been erected for the manufacture of the material, some of these plants being capable of turning out many thousands of tons a week. Thanks in great measure to this form of construction, the streets and roads in America are said to have greatly improved during the last few years, and many experts, analytical chemists, and others, have been, and are busily engaged in the problems associated with the construction and improvement of their roads.

It is the same in this country, and had it not been for the unfortunate war which we were compelled to undertake, further progress would undoubtedly have been made in this direction.

Before turning away from the American practice of their construction of carpets, the author gives the following extracts from a specification of this description of work which has quite recently been approved by the American Society of Civil Engineers.[1]

American Specification.—After describing what is sheet asphalt, in the terms already given, the specification proceeds to describe the materials to be employed as follows:—

"For heavy or medium traffic the so-called close binder should be used instead of the open binder, as the former possesses greater inherent stability than the latter. . . . For a close binder 95 per cent. of the binder aggregate shall pass a screen having circular openings the diameter of which shall be of three-quarter the thickness of the binder course to be laid, the remaining 5 per cent. shall not exceed in their smallest dimensions the thickness of the binder course to be laid. The binder aggregate shall be graded from coarse to fine so as to have the following mesh composition:—

"Passing 10-mesh sieve, 15 to 35 per cent.
" ½-in. screen and retained on 10-mesh sieve, 20 to 50 per cent.

"Total passing ½-in. screen, 35 to 85 per cent."

So much for the binder course, which carries the real carpet, with which the specification deals as follows:—

"The sand for the wearing course shall be carefully graded. For pavements to be subjected to medium or heavy traffic there should be a preponderence of the finer particles and for light traffic there may be a preponderance of the coarser particles. Specifications for a sand for wearing courses to be

[1] *Vide* "Transactions of the American Society of Civil Engineers," Vol. lxxxii., December, 1918, p. 1412.

subjected to medium or heavy traffic should be similar to the following:—

"The sand shall be hard, clean, and moderately sharp. On sifting, it shall have the following mesh composition:—

	Per cent.	
Passing 200-mesh	0 to 5	Total passing 80-mesh and retained on 200-mesh, 20 to 40 per cent.
,, 100-mesh and retained on 200-mesh	10 ,, 25	
,, 80 ,, ,, ,, ,, 100 ,,	6 ,, 20	
,, 50 ,, ,, ,, ,, 80 ,,	5 ,, 40	
,, 40 ,, ,, ,, ,, 50 ,,	5 ,, 30	
,, 30 ,, ,, ,, ,, 40 ,,	5 ,, 25	Total passing 10-mesh and retained on 40-mesh, 12 to 45 per cent.
,, 20 ,, ,, ,, ,, 30 ,,	5 ,, 15	
,, 10 ,, ,, ,, ,, 20 ,,	2 ,, 15	

"The filler should be thoroughly dry limestone dust, or dust from other equally satisfactory stone, or Portland cement, the whole of which should pass a 30-mesh sieve and at least 66 per cent. of which should pass a 200-mesh sieve. The surface mixture should contain from 6 to 20 per cent. of this filler, depending on the kind of sand and asphalt used and the traffic conditions on the street or streets to be paved.

"The specifications should contain detailed requirements covering the physical properties of the asphalt cement, and should prescribe the bitumen content of the binder course and sheet asphalt wearing course mixture. For the grading mentioned, the bitumen should be, for the close binder, from 4 to 7 per cent.; and for the sheet asphalt wearing course mixture, from 9·5 to 13·5 per cent.

"The broken stone for the binder should be heated to a temperature between 107° C. [225° F.] and 177° C. [350° F.]. The sand when mixed with the asphalt cement should have a temperature between 135° C. [275° F.] and 190° C. [375° F.]. The asphalt cement when used should have a temperature between 121° C. [250° F.] and 177° C. [350° F.].

"The asphalt cement and broken stone, or broken stone and sand, for the binder course, and the asphalt cement, sand, and filler for the wearing course, should be thoroughly mixed by machinery until a uniform mixture is produced in which all the particles are thoroughly coated with asphalt cement.

"When brought to the work, the temperature of the binder mixture should be between 93° C. [200° F.] and 163° C. [325° F.], and of the wearing course mixture between 110° C. [230° F.] and 177° C. [350 F.]. The binder course and the wearing surface should be compacted separately by rolling with a self-propelled roller weighing not less than 200 lb. per inch of width of tread, the rolling being carried on continuously at the rate of not more than 200 square yards per hour per roller until a satisfactory compression is obtained. Excessive use of water on the steam roller while compacting the courses of the pavement should not be permitted. During the rolling of the wearing course, a small quantity of Portland cement should be swept over the surface. In cases where sheet asphalt is constructed next to the curb it is advisable to coat the surface, for a space of 12 ins. next to the curb, with hot asphalt cement."

This concludes the American specification which should be carefully perused.

No English specification has yet been prepared as a "standard," which the above American specification may be assumed to be, but Colonel Crompton has prepared and issued a specification of which he has most kindly allowed the author to make use in this book. This specification is as follows:—

COLONEL CROMPTON'S SPECIFICATION.

"*General.*—The surface to consist of two coats, a lower or strength coat, hereafter called 'B,' covered by a wearing coat, hereafter called 'A'.

"*Material for 'B' Coat.*—To be an aggregate of broken stone, chippings, gravel, or ballast and sand, specified in detail in Schedule No. 1,[1] coated and mixed with a binder which may either be the fluxed coal-tar pitch specified in Schedule No. 3,[2] or the fluxed bitumen as specified in Schedule No. 4.[3]

"*Material for 'A' Coat.*—To be graded crushed stone or selected sand with a proportion of limestone or destructor furnace dust, or dust obtained from old road material, filler as specified in Schedule No. 2,[4] coated and mixed with the fluxed bitumen specified in Schedule No. 4.

[1] *Vide* p. 191. [2] *Vide* p. 192. [3] *Vide* p. 194. [4] *Vide* p. 192.

"*Heating and Drying the Aggregates for the 'B' and 'A' Coatings.*—It is advisable that the broken stone, gravel, and sand for the aggregates should be wind-dried as far as possible before being heated for coating purposes, and for this purpose it may be convenient that the fine material should be kept separate. The final drying and heating immediately previously to mixing and coating should be carried out by one or other of the stone or sand-drying apparatus which are now in the market, preference being given to those forms of apparatus which dry the aggregate or the sand by passing over or through them a current of heated air, the temperature of the air being regulated to ensure an even and regular heating of the material.

"For experimental work, patching or other small scale work, the drying and heating can be carried out on hot plates supported on dwarf walls and heated by coke fires underneath them, provided that sufficient care is taken by constantly turning over the material to ensure that no part of the stone or sand aggregate is heated above 400° F., or, if the mixing is carried out on the floor itself, that the temperature at the time the binder is added does not exceed 250° F. for fluxed pitch, or 350° F. for fluxed bitumen.

"*Mixing the Binder with the Aggregate.*—Several forms of mixing plant are available for this purpose, but preference should be given to those forms called batch mixers, into which a given quantity of aggregate can be measured and the binder gradually added, whilst the mixture is being mechanically stirred and incorporated. When the mixing is thorough and complete the mixer should be so arranged that the whole of the contents can be emptied into the transporting vehicle, and the inside of the mixer left clean and thoroughly free from particles of adhering aggregate or sand. This cannot be so well ensured when continuous mixers are used as in this latter case it is not easy to maintain an accurate proportion between the aggregate and the binder, and the aggregate itself is likely to be altered by the finer particles having a tendency to adhere to the sides of the mixer near its mouth or opening, which leads to irregularity in the grading of the coated mixture, "For carrying out work on a small scale, mixing can be carried out by hand on heated plates by shovels, forks, or rakes, provided that it is done with extreme care and watchfulness to ensure regularity and to prevent the overheating above referred to.

"The clerk of the works or the foreman supervising the work at the mixing point must see for himself that not only is every piece of stone aggregate covered with the binder, but that the sand is also properly coated, and that every stone is coated not only with the fluxed pitch, but with coated grains of sand adhering to it.

"*Proportion of Fluxed Pitch to the 'B' Aggregate.*—The fluxed pitch mixture necessary to be added to the stone and grit and sand graded aggregate should lie between 11 to 12 gallons by measurement to the ton of stone and sand, or if a weighing method is preferred between 112 lbs. and 130 lbs. of fluxed pitch to each ton of 2,240 lbs. of aggregate, including its sand, thus ensuring that the resulting mixed aggregate will have a binder content as nearly as possible 5¼ per cent. by weight.

"*Proportion of Fluxed Bitumen and Filler to the 'A' Aggregate.*—For rural roads to each ton of graded grit or sand must be added 675 lbs. of ground limestone or other dust as filler, and 532 lbs. or about 5·3 gallons of fluxed bitumen. The content of the graded material will then be:—

Graded grit and sand . . .	72·8 per cent.
Fluxed bitumen	11·6 „
Filler	15·6 „

"*Melting and Mixing Fluxed Bitumen with Sand and Filler.*—The melting of the bitumen must be carried out in closed kettles. These may be heated by steam or hot air coils or by direct injection of steam at the required temperature so as to prevent irregularity in heating and consequent loss of flux. The temperature should not exceed 330°, the sand must be heated separately to the same temperature. The same mixer as employed for the 'B' coating may also be employed for the bitumen, grit, and sand, "*Testing the Mixture for the 'A' Coating.*—From the first batch and from every succeeding tenth batch, according to the magnitude of the work, test cylinders should be prepared as follows and set aside for testing and record purposes. Test moulds should be provided by the contractor consisting of hardened hollow steel cylinders 2 ins. long and 2 ins. external diameter, accurately ground out after being case-hardened to be a good push fit for $1\frac{1}{4}$-in. Whitworth standard gauge. A massive steel base should be provided, having on its upper surface a cylindrical projection $\frac{1}{8}$ in. high by $1\frac{1}{4}$ ins. diameter to fit accurately into the hollow cylindrical mould, also a hardened steel plunger not less than $2\frac{1}{2}$ ins. long should be provided; this should be ground all over to ensure that the ends are perfectly true and square, and that the plunger accurately fits the bore. For convenience not less than six of the hollow cylinders should be provided, two plungers, but only one base. To prepare the test cylinders about 50 grammes of the hot mixture from a batch at the completion of the mixing should be filled into the mould cylinder when it is resting on the cylindrical base and held centrally thereon by the projection. The plunger must be inserted and driven down by a few blows of a mallet and finally compressed by a screw jack or bench vice. When cold the compressed cylindrical sample is to be forced out and marked and numbered for identification with red chalk, pencil, or other convenient means.

"*Tests for the Cylinders.*—The cylinders are to be weighed in grammes, and their length taken by callipers, and their density thus obtained. The density of the cylinder should lie between 2·5 down to 2·0 when beach or dredged sand is used with dust filler, and between 2 and 1·8 when crushed flint gravel is used in place of the sand. The cylinders must be tested in a press between two flat surfaces, the pressure being applied truly to their flat ends. A pressure of 500 lbs. applied for one minute must not shorten the cylinders more than 3 per cent. at 77° F. or 8 per cent. at 100° F., and in neither case must cracks show themselves on the external cylindrical surface.

"*Percussion Tests.*—The cylinders must stand not less than eight blows delivered by the ball end of a hammer rounded to

1 cm. radius, the head of which weighs 1 kg. [or 2·2 lbs.] falling through a distance of 9 ins. [or 23 cm.] equal to about 20 foot-lbs., and guided so that the blow falls accurately and centrally on the end of the cylinder. The number of blows to be counted until the first crack appears.

"*Test for Water Absorption.*—The test cylinders must not increase more than ½ of 1 per cent. of their original weight after immersion in water at a temperature of 60° F. for twenty-four hours.

"*Transport of the Mixture to the Spreading Point.*—The most convenient and economical method of transporting the coated aggregate for the 'B' crust or the sand and bitumen for the 'A' crust from the point at which the coating is carried out to that where it is spread on the road will vary with the distance. For short distances up to 100 yards the materials can be transported in iron barrows, but for longer distances carts or waggons, lined with iron and covered with tarpaulins so as to prevent loss of heat, are useful and advisable. For still longer distances motor waggons can be obtained specially adapted for the purpose, so that the heated mixture can be delivered at points up to 15 or 16 miles from the mixing point, and delivered at a good working temperature not below 175° F. for the fluxed pitch aggregate, or 200° F. for the bitumen aggregate.

"*Spreading the Mixture for the 'B' Crust.*—There are two methods of spreading. Either the material should be tipped on to metal plates placed at one side of the road on the verge from which it can be conveniently thrown, shovelled, or raked over the surface to be coated, or it can be raked direct from the back of a waggon provided with means of tipping or inclining the floor of the waggon to facilitate the work. The thickness of the spread material must be regulated so as to give the required finished thickness, allowing about 30 per cent. for compression under the roller. With crushed limestone, flint, gravel, or similar material of the same specific gravity, 1 ton of the coated mixture should be found sufficient to cover 8 super yards to a final compressed thickness of 3 ins. for the 'B' coating.

"*Rolling the 'B' Coating.*—When the aggregate consists of flints, or flint gravel, or any stone which is of a tender description, the roller first passed over should not be loaded to more than 2,000 lbs. per lineal foot of roller surface, but as soon as the temperature has fallen so that the surface is no longer perceptibly warm when the back of the hand is applied to it, the work may be finished with the ordinary 10-ton roller, which has usually from 3 to 3½ tons per foot of roller width.

"*Finishing the Surface of the 'B' Coating.*—The surface of the 'B' coating which is not intended to take the traffic direct should be left in a rough condition so as to afford a key for the following 'A' coating.

"*Explanatory Remarks as to the Strength of the 'B' Coating Specified.*—By this specification surveyors can obtain a 'B' coating of great capacity to transmit and spread the weight of the traffic over an increased area of the sub-crust or foundation. As the 'B' coating will be voidless and contains an unusual proportion of binder, its strength, when cold and well consolidated, will be such that 2 ins. of it is equal to 3 ins. of the ordinary tar macadam made with large stones and having the usual proportion of voids. This economy in material is obtained by the careful grading of the material and by ensuring that every graded stone, from the largest down to the sand itself, interlocks with and mutually supports the other stones, and by this interlocking enables a more ductile binder to be used, which, being so ductile, is self-healing in quality, and will allow a road to adjust itself and continue to maintain a strong waterproof surface even if considerable subsidences of the foundation or of the sub-crust have taken place; on the other hand, this interlocking prevents any considerable movement taking place under traffic conditions, and hence reduces the tendency to waviness under heavy high-speed traffic in hot weather, but in cases where there is no foundation, and especially where the road had previously given trouble from the softness of the subsoil, it is more economical at such points to increase the thickness of the 'B' coating than to interfere with the foundation.

"*Spreading of the 'A' Coating.*—In most cases it is advisable that the 'A' coating should be applied as soon as the 'B' coating is finished, and before any dirt or dust has settled on the latter, as in this way the two coats can be cemented together with the greatest certainty. If from any cause this cannot be carried out, and any time has elapsed before the 'A' coating is applied to the 'B' coating, the surface of the latter must be carefully cleansed from all mud, dust, or loose particles. If rain has intervened before the 'A' coating can be applied it is advisable to use one of the surface heating devices that are now available for drying and heating such surfaces.

"In all cases it is more convenient and economical to rake the mixture direct from the back of the cart down an inclined plane to the cleansed surface of the 'B' coating, the vehicle being moved forward until a sufficient quantity is spread on to the road for rolling purposes. The width to be spread at one time must vary with the width of the road, but in all cases it is desirable that the longitudinal joint of the two widths should not come exactly in the line of the natural wheel tract. The thickness should be carefully regulated by raking with gauging rakes provided with smooth teeth shaped so as to move easily over the existing road surface and act as a gauge for the thickness of the mixture.

"It will be found that the mixture usually compresses 30 per cent. in rolling, and the gauged rakes must be set to suit. When using natural grit, sand, and with a mixture of an average density of 2·0 tons, the mixture should cover about 20 yards super, and roll down to a finished thickness of 1 in.

"*Rolling the 'A' Coating.*—After spreading and regulating, the surface must be levelled by a very light roller not weighing more than ½ cwt. per foot of roller width. This rolling should not be commenced until the temperature at the surface has fallen to about 130° F., which can be ascertained by laying the back of the hand on the raked surface. The light rolling should be carried out until the surface is formed to the correct shape, and has cooled down to a summer air temperature, or in winter to a temperature of about 70° F.

At this point a 10-ton roller can be brought over the work to finish the consolidation."

The schedules referred to in the above specification are as follows:—

SCHEDULE NO. 1.

Specification of Aggregate for "B" Coating.—*General.*—As the "B" coating is not exposed to surface wear but is only to support and spread the weight of the traffic, an aggregate made of many of the cheaper stones may be used, although they may not be hard or tough enough to take surface wear. Therefore, in addition to old stone scarified from the old road surface, limestone, sand, gritstone, slag, gravel, or ballast may be used, provided that in all cases a large proportion of the material has been recently crushed so that new and clean surfaces of the stones may be thus exposed. In any case it is important that no considerable percentage of the aggregate should have been left exposed to the weather so that the stones are partly coated with adherent dust or dried mud.

Grading.—There are crushers now offered to surveyors which can be arranged to crush at one operation stone or old road material down to the 1½-in. gauge stone and finer material hereunder specified, and which can be said to conform sufficiently accurately with the following requirements, namely, that 1 ton of the aggregate must contain:—

Not less than Per cent. Cwt.	Not more than Per cent. Cwt.	Passing British Standard Screen.	Retained on British Standard Screen.
35 or 7	45 or 9	1½ in.	½ in.
12½ ,, 2½	17½ ,, 3½	½ ,,	⅜ ,,
12½ ,, 2½	17½ ,, 3½	⅜ ,,	⅛ ,,
30 ,, 6 of fine material or sand passing ⅛ in.			

The correctness of this grading must be from time to time ascertained and corrected by the inspector or clerk of the works, who must, for this purpose, provide himself with a set of four British standard sieves or screens having square apertures of 1½ ins., ½ in., ⅜ in., and ⅛ in. respectively.

SCHEDULE NO. 2.

Specification of Aggregate for the "A" Coating.—*General.*—The aggregate for the "A" coating to be graded silicious sand or grit sorted from crushed rock, all of which has passed a screen having apertures $1\frac{1}{2}$ ins. square, and which on testing by a set of British standard sieves shall be found to contain not more than 66 per cent. of grit retained on a sieve having $\frac{1}{16}$ in. or ·0625 apertures. A close approximation to this grading gives the best result, and precautions must be taken by the foreman to see that the grading of the aggregate that he fills into each batch in the mixer should not be materially different from the above. He must, therefore, whenever the supply is replenished from new sources, ascertain that it conforms generally with this grading, any excess or deficiency of the grades being reduced or supplemented by additions of sizes which the tests show to be deficient. The 66 per cent. of the coarser grit is advisable to give good foothold to the finished surface, and the fine material is that necessary to render it tough, close-grained, and waterproof.

Filler.—To the aggregate must be added approximately 15 per cent. of finely ground limestone, clay, or dust, sifted from old road material, or from destructor furnaces, and in this case the whole of the particles must be fine enough to pass the lowest or standard 0·0033-in. sieve, and of all that which passes through the sieve, when it is mixed with water, and well agitated by blowing air through it, not more than 40 per cent. must settle in 15 seconds, so that 60 per cent. can be poured off with the water 15 seconds after agitation has ceased.

SCHEDULE NO. 3.

Specification of a Fluxed Pitch Binder for the "B" Coating.—The fluxed pitch binder to be commercial soft coal-tar pitch derived wholly from tar produced in the carbonisation of bituminous coal, except that it may contain not more than 20 per cent. of pitch derived from tar produced in the manufacture of carburetted water gas. On distillation the pitch shall yield below 270° C. not more than 1 per cent. of distillate;

between 270° and 315° C. not less than 2 per cent. and not more than 5 per cent. of distillate. The free carbon in the pitch should not exceed 35 per cent.

Fluxing Oil.—The oil for fluxing pitch shall be derived wholly from tar produced in the carbonisation of bituminous coal. It should be the heavy oil which comes over last in the distillation of tar and pitch, and is that known commercially as heavy oil, green oil, or anthracene oil. Its specific gravity shall lie between 1·070 and 1·085 at 38° C., at which temperature the oil shall be commercially free from solid matter. It shall be commercially free from water, light oils, and middle oils, and on distillation shall yield not more than 15 per cent. of distillate below 270° C. [temperature taken in vapour].

The pitch shall be fluxed by first pouring into the pitch boilers a quantity of the fluxing oil equal to about 12 per cent. of that of the pitch that is intended to be added. The pitch must be added very gradually, but before the whole of the pitch is poured in, samples must be taken and tested for viscosity by penetration on a Smith and Dow or other standard penetrometer. The test of the sample must be taken in a sample tin not less than 2 ins. in diameter by 1 in. deep immersed in water carefully maintained at 77° F. for a sufficient time to ensure that the pitch itself has acquired the same temperature as the water. The penetration must not be greater than 50° or less than 70°, with the needle loaded with 100 grammes for 5 seconds. It is desirable that the first sample should be taken when the material is known to be too soft and the penetration is greater than 70°. Additional pitch should be added, and further samples taken, and tests made until the pitch is found to be as nearly as possible to the 60° penetration. It will be found that every time the pitch is remelted its viscosity will increase, but as soon as the 50° limit is reached additional heavy oil flux must be added.

For the above reason the pitch and oil-fluxed binder being extremely sensitive to over-heating, care and watchfulness must be exercised to ensure that at no time the temperature of the fluxed pitch binder, whether in the boiler or afterwards in the act of mixing, shall exceed 300° F.

SCHEDULE NO. 4.

Specification of a Fluxed Bitumen Binder for the "A" Coating.—The refined bitumen to be used for road surfacing mixtures herein specified shall be obtained in the following manner:—

The bitumen to be a residual prepared by the careful distillation of asphaltic petroleum until the resulting residual, which is herein called bitumen, has a consistency not harder than 30 penetration at 77° F.

Samples of bitumen taken at random from each lot provided by a contractor shall conform with the following conditions 1 to 3 herein mentioned:—

(1) All consignments of bitumen shall be marked with a lot number denoting place of origin and with their hardness in degrees of penetration, and ten samples taken at random from each lot shall not vary more than 15 per cent. from the average penetration provided that no part of any shipment shall be below 20 penetration at 77° F.

(2) The average of the solid bitumens so obtained shall be soluble in carbon tetrachloride to the extent of 98½ per cent.

(3) When 100 grammes of bitumen are heated and maintained for 5 hours at a temperature of 325° F. in a flat tin vessel, not less than 4 ins. in diameter, it shall not lose more than 5 per cent. of its weight after 5 hours of continuous heating, nor shall the penetration at 77° F. be less than half the penetration taken before the 5 hours' test was commenced.

By heating natural asphalt to a temperature not exceeding 100° F. until all water has been driven off. The term "natural asphalt" means any natural mineral bitumen, either pure or mixed with foreign matter, from which, through natural causes, the light oils have been driven off until it has a consistency harder than 70 penetration at 77° F. At least 98½ per cent. of the bitumen content, and which is soluble in cold carbon bisulphide, shall be soluble in cold carbon tetrachloride, but in no case shall such bitumen be prepared at a refinery by the use of any product which is not hereafter provided for.

Fluxes.—The fluxing material may be an asphaltic, a semi-asphaltic, or, in certain cases, a paraffin residue, which, when added to the bitumen, shall conform to the required tests for penetration and ductility.

The flux must have a penetration greater than 20 when tested with a needle at 77° F. loaded with 100 grammes for 1 second. It must be soluble in cold tetrachloride to the extent of 99 per cent., and must not harden notably after heating for 5 hours at 400° F. The residual fluxing oil from an asphaltic base shall have a specific gravity of not less than 0·098, nor greater than 1·04 at 77° F. The semi-asphaltic residual oil, after evaporation at 500° F. to a solid bitumen of a consistency of 50 penetration, shall have a ductility of not less than 30 cm. or 11·81 ins. at 77° F. The paraffin flux shall have a specific gravity of ·092 to ·094 at 77° F. It shall not flash below 350° F. when tested in a closed oil tester. It shall not lose more than 5 per cent. of its weight when heated for 5 hours at 325° F. in a tin box 4 ins. diameter, and the residue after heating shall flow at 77° F., shall be homogeneous, and shall show no coarse crystals.

A semi-asphaltic fluxing oil shall have the same general characteristics as the paraffin residual, except that its specific gravity shall lie between 0·94 and 0·98 at 77° F.

The bituminous binder prepared from the materials above specified shall be made up from the refined bitumens and the fluxes specified by the addition of the oil in such proportions as to produce a bituminous binder of correct consistency measured by penetration. When it is found that the weight of flux in the bituminous binder prepared from solid natural asphalt exceeds 25 per cent. of the weight thereof, only asphaltic or semi-asphaltic fluxes may be used, and the specifying engineer may, if he desires it, require that the bitumens and fluxes which form the bituminous binder shall be weighed separately, either in his presence or in the presence of his authorised inspector. The process of fluxing the bitumen shall be carried on in a suitable vessel at a temperature ranging from 250° F. up to and not exceeding 375° F. The mixture shall be thoroughly agitated by mechanical means or by blowing steam through it until the resulting binder has been thoroughly mixed, and there is no tendency, after samples are cooled, of any portion of the flux separating and showing at the surface of the sample.[1]

It must be understood that where the use of refined asphalts is allowed, only asphaltic or semi-asphaltic fluxes may be used except in certain cases where the solid natural asphalt is of such a character that it can be fluxed by a paraffin flux without the addition of any other material, so as to produce a bituminous cement which will comply with the requirements set forth under that head. If these requirements are complied with any of the fluxes specified elsewhere may be used.

The bituminous binder must always be of uniform consistency throughout, and if any portion is found to settle in the heating vessel between the intervals of using it, the whole must be thoroughly agitated before any portion of it is drawn for use.

The consistency of the bituminous binder shall be made to conform with the penetration tests laid down in the table hereunder, and the contractor may be required to raise or lower the whole scale of penetrations in order to suit special requirements of climate or traffic, but the ratio of increase of penetration due to increase of temperature shown in the table must be maintained.

If 100 grammes of the bituminous binder fluxed to the desired degree of penetration be heated in a flat vessel 4 ins. diameter continuously for 5 hours at a temperature of 325° F., it must not lose more than 5 per cent. of its weight nor shall its penetration at the completion of the test be less than half the penetration measured before the test was commenced.

Penetration Tests.—The penetration tests must be measured with a Smith and Dow or similar penetrometer with a No. 2 needle weighted to a 100 grammes for a period of 5 seconds, each degree being equal to one-tenth of 1 mm. penetration :—

[1] Note, fluxing, which is a difficult operation requiring special experience, had better be left to the suppliers of the bitumen, who should be made responsible that their bitumen is fluxed to fulfil the penetration conditions herein laid down.

When Tested in Water at Degrees F.	Penetration in Degrees.
32	10 to 15
77	60 „ 70
100	130 „ 140

Ductility Tests.—Ductility tests shall be carried out in a Smith's or other approved ductility testing machine in the same manner and at the same rates of extension as prescribed for the bitumen itself, but when the consistency of the bituminous binder varies from 50 penetration the requirements as to ductility shall be modified by the addition of ·875 in. for each 5° of penetration above 50, and be reduced in the same proportion for each 5° of penetration below 50, but the ductility at the maximum penetration permitted, which is 70 at 77° F., must not exceed 1 metre, nor at the minimum penetration permitted must not fall below 6 ins.

The above specification and schedules are very complete, and although future experience may show that modifications in the "mix," or methods of preparation, may be advisable, they form an excellent basis on which to frame a specification, and they show the great care, work, and investigation that must have been devoted to their preparation.

Importance of Care.—It is evident that to secure success, great care is necessary in the selection of the materials to be used, their correct grading and method of mixing. In dealing with a semi-chemical, semi-mechanical process of this description much must be left to work in the laboratory, and in reading Colonel Crompton's specification it is clear that he is anxious for samples of the materials, and of the finished road work, to be frequently taken and submitted to tests in order to make sure that the material is of the proper composition and character.

With regard to the bitumen, there are some excellent trade "compounds" on the market which can be relied upon as suitable for this class of work, and in the majority of cases, where a surveyor has not the means at his command to make elaborate tests and experiments, it is better to rely on these trade compounds rather than attempt to "make up" a suitable material.

Machines.—With regard to the cleansing, drying, and heating of the materials for the aggregate, the proportion of the filler, and the application of the bitumen at the proper temperature, there are some excellent machines on the market, specially designed for the purpose, which thoroughly cleanse the materials, dry, heat, and mix them with a modicum of labour. It would be useless to describe these machines, as each road engineer must be guided in his choice of a machine by his local requirements.

Various Descriptions of Carpets.—There are a number of descriptions of carpet work of which the following may be given as an example:—

"Speaking generally, only about one-tenth of the weight should consist of grit or granular particles passing a 6-mesh sieve and retained on a 10-mesh sieve; about 40 per cent. should pass the 10-mesh and be retained in the 36-mesh, another 40 per cent. passing the 36-mesh and retained in the 100-mesh, with 10 per cent. only passing the 100-mesh.

"In order that such a graded aggregate may be cemented by the binder with a solid rock-like sheet to form the road surface, it should have added to it about 10 per cent. of fine limestone powder or Portland cement as a filler and about 12 per cent. of pure bitumen as a binder."

Another mix of a coarser "grain" and one that turned out to be less slippery than some of these artificial carpets is as follows; the material used throughout was crushed or pulverised hard basalt rock in the following proportions:—

48·8 per cent. passing $\frac{1}{4}$-in. sieve and retained on $\frac{3}{8}$-in. sieve; 11·6 per cent. passing $\frac{1}{8}$-in. sieve and retained on $\frac{1}{16}$-in. sieve; 16 per cent. passing $\frac{1}{16}$-in. sieve and retained on 208-mesh sieve. To which was added 16 per cent. of a fine dust filler, and 8 per cent. of "bitumen" of a special "brew".

Another "recipe" is one where the aggregate was of a fine sharp pit sand which had to be graded in the following proportions:—

10·7	per	cent.	passing	100-mesh	sieve.		
15·7	,,	,,	,,	76	,,	,,	
45·7	,,	,,	,,	50	,,	,,	
10·0	,,	,,	,,	40	,,	,,	
10·6	,,	,,	,,	30	,,	,,	
4·6	,,	,,	,,	20	,,	,,	
1·5	,,	,,	,,	10	,,	,,	
1·2	,,	,,	retained on	10	,,	,,	
100·0							

The filler used was either Portland cement or dust of a mineral nature of equally fine texture of which 9 per cent. was added; the sand equalled 78 per cent. and the "bitumen" 13 per cent.

This was laid on the road at a very high temperature and rolled. The result was fairly satisfactory.

One of the most modern developments in this "carpet" work is that in connection with the use of the clinker from house-refuse destructors as an aggregate, of which the following is an example:—

Destructor Clinker Aggregate.—Mr. E. J. Lovegrove, M.Inst.C.E., the Borough Engineer of Hornsey, has for some years been engaged in experiments for the utilisation of this waste material in carpet work, and was the pioneer of the movement which is now spreading in this direction.

He has constructed a large number of roads with this material, many of the earlier lengths having been subjected to very heavy traffic, including motor omnibuses, for a period of upwards of five years, and these roads have worn exceedingly well.

Mr. Lovegrove's methods may shortly be described as follows:—

The clinker is prepared by milling and pulverising to obtain the fine aggregate for the top coat or wearing crust, and the coarser material for the bottom coat. The aggregate for the top coat varies from $\frac{1}{8}$-in. down to fine powder, and that for the bottom coat from about $\frac{1}{2}$-in. to $\frac{3}{16}$-in. gauge.

The aggregates in each case are mixed hot with bitumen and conveyed to the road and laid and rolled while hot.

The surface of the old macadam carriage way was previously prepared by scarifying to a depth of about 3 ins., the loose material removed, and the rough surface swept clean.

The bottom coat is then laid and rolled longitudinally with an 8-ton steam roller to a consolidated thickness of about 2 ins. The top coat is then spread and cross rolled with a hand roller weighing 6 cwts. and is afterwards rolled longitudinally with the steam roller, to a consolidated thickness of about 1 in. to $1\frac{1}{8}$ ins.

The surface is then dusted over, either with fine clinker powder or Portland cement, and the traffic can be turned on to the road within five hours of the laying.

When laid and consolidated this material closely resembles natural rock asphalt either compressed or mastic, and is superseding this natural material for both carriage ways and footpaths. The fine clinker "asphalt" has been laid on streets up to gradients of 1 in 24, and beyond this a coarser graded material is used. Mr. Lovegrove is now engaged on experiments to see if even steeper gradients can be paved with this material, up to even a gradient of 1 in 8.

The bitumen used throughout in the work has been mexaphalt.

The result of Mr. Lovegrove's work in this direction has been remarkably successful and the cost very reasonable, as might be anticipated when the use of such a waste material as the clinker from a house-refuse destructor can be made available. It is certainly a great development in the evolution of bituminous roadways, and other engineers are engaged on experiments with this material.

An inspection of Mr. Lovegrove's roads in Hornsey shows that he has attained as near perfection in road making as is possible. His clinker carpet roads withstand the heaviest traffic, they require no surface tarring after being laid, they are dustless and require no watering, scavenging is reduced to a minimum, they are non-slippery, they are laid close up against some of the tramway rails without moving or wearing, they are very economical in construction, and their life apparently is a long one, without any necessity for repairs. This success has only been achieved by the most patient and scientific investigation which is still continued, but so far as the author has been able to investigate the present position of modern road construction, he is of opinion that Mr. Lovegrove, with his methods of refuse destructor clinker road construction, has reached the high-water mark of our knowledge of bituminous carpets.

CHAPTER VII.

WAVES AND CORRUGATIONS.

Sidcup Trials and Waves.—In connection with the well-known "Sidcup Trials," Colonel Crompton, C.B., the Advisory Engineer to the Road Board, suggested, in the year 1912, that careful measurements of the surfaces of roads should be undertaken, and he devised an ingenious arrangement for this purpose, which in process of time revealed, *inter alia*, an important point in connection with those changes which take place in the surfaces of roads, which are variously called waves or corrugations. They were then usually attributed to the wear of the surface, but these measurements proved that this was not the cause, but that there was an actual movement, or deformation, of the surface; there was no loss of material due to wear, but the material had been pressed down in the hollows and had been pushed up in the form of waves, the summits or crests of which were found to be actually higher than the original level of the road surface.

Colonel Crompton gave considerable attention to this question of waves, and made a report thereon, in which he stated, *inter alia* :—

"**Theory of Wave Formation.**—It is very probable, although not actually proved, that the wave formation is probably due to the speed of the vehicles. In the days of horse-drawn traffic the average speed was very much lower; the action of the wheel on the road surface more nearly approached a true rolling movement, whereas at the higher speeds now attained by all classes of vehicles, from the heavy motor lorry running at 8 miles an hour with 8 tons on the back axle up to the high-speed motor car at 35 miles per hour with 1 to 2 tons only on the back axle, the wheels do not roll smoothly over the road but only touch the surface occasionally, and the wheel progresses by a series of bounds, a blow being given to the road surface each time the wheel strikes it."

"**Harmonic Blows.**—This succession of blows or percussive action of modern vehicles must be rhythmical or harmonic in its action, the number of blows the road surface receives per second depending on several factors, the speed, the weight, the springing, the diameter of the wheels, and so forth.

"This harmonic action shows itself at its worst when vehicles having the same harmonic features, such as a line of motor omnibuses, constitute the principal tonnage passing over the road. I observed it with great care during the time the Fortis Green Road, at Hornsey, was being reconstructed. The same action could be observed to great advantage on the road from Barnet to St. Albans soon after motor omnibuses were first started, and the instances might be multiplied."

"**Length of Waves.**—The length, measured from summit to summit or hollow to hollow of the waves produced by motor omnibuses, apparently varies between 16 ins. on hard surfaces up to 2 ft. on softer surfaces. The lengths of the waves are not quite regular and are probably modified by the harmonic features of the other vehicles which traverse the road, but I think there can be no longer any doubt that the harmonic action exists, and that it is one of the main features in modern traffic which will hasten repair or reconstruction.

"Our road surfaces, as now constructed, resist this tendency to wave formation in various degrees. Well-made asphalt laid on concrete shows it least; next comes wood pavement laid on concrete which shows it slightly; then comes some of our modern constructions exemplified on our trial roads, which show it in various degrees, and amongst these I think pitch grouting has shown it most of all. . . .

"It has shown itself in water-bound macadam on which surface tarring has been carried out for several years successively. In these cases the actual wear by removal of material in the form of mud or dust has been very small, and the real wear has been below the surface by the stones moving under the tarred crust producing small material and facilitating the movement or translation of the rounded stones from points immediately below the hollows to the crests of the waves."

Colonel Crompton measured waves on the surfaces of several roads near London and "found that wave lengths of from 16 ins. to 24 ins. are very common, and . . . the total height from trough to summit of the wave is as much as $\frac{3}{4}$ in.".

Is Rolling the Cause?—It is contended by some road engineers that these waves originate with the rolling during construction, as otherwise there is no reason why they should commence at all, and that if the surface is absolutely smooth there could be no blows given to the surface as the wheels of vehicles would travel evenly and smoothly over the surface. No doubt, if once started, the tendency to form waves would be increased by the "harmonic" action of the traffic.

Hot or Cold Laying the Best.—It is also affirmed that waves are more prone to be formed when the bituminous macadam or carpet is rolled whilst hot. A surveyor stated recently: "In one case where rolling had been permitted with a $7\frac{1}{2}$-ton roller, the temperature of the material being as high as 300° F., on a carpet of $1\frac{1}{4}$ ins. thick, the result was that it became impossible to avoid corrugations at intervals of 3 to 4 ft. In another case rolling was carried out at a temperature of about 200° F., the material being hand rolled in a transverse direction previously; the effect on the surface was almost to avoid the formation of corrugations."

The above statement is not very clearly put; he must have meant waves and not corrugations when speaking of the length of these undulations at intervals of 3 and 4 ft., nor is it quite clear in the second case whether there was any longitudinal rolling as well as transverse rolling.

This theory, however, as to waves being caused by rolling the material when hot is disputed by other engineers, and there is no very authentic information either one way or the other on the subject.

Waves or Corrugations.—It would be well at this point to decide what are waves and what are corrugations. The former are really undulations of some appreciable length, say of some 12 ins. or more; the latter are more in the form of "ripples" of very short length, and are, in the author's opinion, of quite a different nature and character to waves. They do not arise, in his opinion, from rolling, but are caused by either some defect in the composition of the material, or from changes in the atmospheric temperature, or partly from both causes. They may, however, arise from rapid and heavy traffic, for corrugations not only affect roads, but also tramway rails and railways, and in these cases have been traced to the composition of the steel rail; it has been stated, "the extent of corrugation in a rail is in inverse ratio to the amount of carbon, or other hardening elements, in the rail," and naturally the plastic nature of a bituminous road surface renders it liable to corrugations under certain conditions. Fortunately, however, very few roads show any signs of corrugation, but unfortunately a great number of roads become wavy under modern traffic.

Colonel Crompton, in a paper which he read at a meeting of the Institution of Mechanical Engineers, in 1913, went into the question of waves very minutely.

Colonel Crompton's Theory.—He pointed out that when a wheel rolls over any surface, "the individual particles of which that surface is composed must be rocked to and fro by the rolling action of the wheel," and that in the case of a road made up of particles of regular size, this rocking causes them to rub against each other and their edges abrade, and the particles become rounded and spherical in form. "In a well-designed newly made road, angular pieces of stone of a definite gauge are used; the voids between these stones are partly filled with smaller angular pieces and with sand and fine material, so that when the whole is consolidated by the roller the rocking action of the wheels of the traffic is resisted to some extent by the angular inter-locking of the stones and sand." As they lose their angles, however, and become rounded, they begin to roll over and transfer themselves to new positions under the action of the traffic.

"This has a greater effect on the larger than on the smaller stones, so that in practice . . . one finds the smaller rounded stones underneath the troughs and the larger stones underneath the crests of the waves."

He contended that wave action had been accentuated by self-propelled traffic, as "the speed being greater, the change from true rolling to pulsating action is therefore greater," the wheels being also of smaller diameter and more equal in size added to the harmonic characteristics of the traffic. He referred also to the hammering effect of the horses hoofs modifying and rectifying the wave tendency, and that "in all essentials the conditions of horse-drawn traffic were far more heterogeneous and non-harmonic than the new traffic".

Interest of the Subject.—The author can add very little to the admirable and suitable explanation as to the cause of waves, given above. The subject is of extreme interest and still requires further investigation. The author has seen a bituminously bound macadam road with considerable waves and deformations before it had received hardly any traffic at all on it. There is a broad gravel footpath in one of the London parks that has no wheeled traffic on it, except a few perambulators and bath-chairs, which is as wavy as the sea! In neither of these cases could the waves be attributed to traffic, but they might both be attributable to original rolling, or to changes of atmospheric temperature.

Waves on Paving.—With reference to waves which are stated to be seen on the surface of wood blocks, asphalt, and even occasionally on a granite sett pavement, the author is of opinion that the observers in these cases have confused settlement or some other cause for the true wave which arises in the body of the material itself. The so-called waves in wood blocks may arise either from the settlement of a certain group of blocks on their foundation, or from the swelling and expansion of the blocks causing them to rise in the form of an arch in certain places, or from their being pushed by the traffic slightly out of line which gives them the appearance of waves. With regard to asphalt and granite sett pavement the so-called waves may be caused by the unevenness, or weakness, of the foundation, which causes settlements and consequent rises and hollows on the surface.

Suggestions as to Causes of Waves.—To sum up the various theories which have, from time to time, been raised on this question of waves, the author submits the following short list which he believes embraces most, if not all, of them :—

(1) Commenced by the original longitudinal rolling.

(2) The harmonic action of the wheels of the traffic causing a series of repeated blows, tending to depress the surface into a succession of more or less regular troughs.

(3) An actual movement in the plastic mass of which the road surface is composed, caused by the harmonious pushing or pulling movements of the wheels of the mechanically propelled vehicles.

(4) The action of atmospheric changes of temperature, which either expand or contract the material, thus causing deformation.

(5) The lack of a stable foundation.

(6) The uneven surface of the foundation.

(7) Some defect in the composition of the bituminous surfacing material, e.g. an indiscriminate mixing of the materials or improper grading of the aggregate.

(8) Laying the material, and rolling it, when not of the right temperature.

Further Research Necessary.—In view of the differences of opinion on this important matter it is evident that further investigation, research, and observation are required. At present the only remedies suggested appear to lie in the direction of either abandoning longitudinal rolling for some other method of consolidation, or the construction of road surfaces with some substance of a more unyielding or tenacious nature.

CHAPTER VIII.

PAVED STREETS.

HAVING dealt with the various descriptions of what are known as "bituminous" roads, for want of a better name, it is necessary to deal with the harder or more durable surfaces of streets, suitable for cities, towns, and urban districts, or where the traffic is known or expected to be of too great a weight and intensity for the softer descriptions of such surfaces.

Selection of Material.—In the selection of a suitable paving material for any carriage way, the gradient of the street or road must be considered. Asphalt would be unsuitable for streets of steeper gradient than about 1 in 50; wood, 1 in 36, and hard stone setts, 1 in 20. Mr. Spalding of the Cornell University in America, stated, that the smoother forms of pavements are only applicable to light gradients, and he gives the following: rock asphalt, 1 in 50; Trinidad asphalt, 1 in 25; brick, 1 in 17; wood, "a little steeper," and stone blocks are satisfactory at about a 10 per cent. gradient [1 in 100]. But Mr. Spalding evidently over-estimated safe gradients for wood, as a steeper gradient than 1 in 17 for such a paved surface would be bordering on a very slippery footing for horses; with the increase of self-propelled vehicles the question of gradient may not be of much importance, but during the transition period through which we are now passing, the point must not be overlooked, although even in their case custom has made them more sure footed on the harder surfaces of streets.[1] For instance, it was stated, quite twenty-five years ago,

[1] A special Committee of the American Society of Civil Engineers, appointed to consider the question of "materials for road construction, and on standards for their proper use," reported in 1918, and, *inter alia*, fixed the following gradients: "stone blocks from 9 to 15 per cent.; wood blocks, 4 per cent.;

that in Berlin there were about one-half the number of falls of horses on the asphalted streets than there were when only one-half the area of the streets were of asphalt, the remainder being then of water-bound macadam.

Requirements of a Perfect Street Pavement.—As President Wilson set the fashion with 14 points, the author submits the following 14 detailed and condensed requirements of a perfect street pavement. Though the ideal is seldom reached it is as well to have a goal of perfection at which we should strive:—

(1) Impermeability.[1]
(2) Durability.
(3) Foothold.[2]
(4) Little resistance to tractive force.
(5) Adaptability to all gradients.
(6) Adaptability to all classes of traffic.
(7) Noise reduced to a minimum.
(8) Ease of cleansing.
(9) Non-manufacture of mud or dust.
(10) Ease of repairs.
(11) Economy in maintenance.
(12) Not requiring excessive camber.
(13) Not influenced by climatic changes.
(14) Easily opened and reinstated.

Foundation.—Even of more importance than in the case of other descriptions of road construction, is the question of the foundation for paved streets, as they are generally called upon to bear very heavy and concentrated traffic. It is the foundation which carries the weight; the material with which the street is paved is merely the skin or veneer to preserve the real roadway, the foundation underneath. Up to now no better foundation has been discovered than that made with Portland cement concrete, and within recent years it has been found

asphalt, 5 per cent.; concrete, 8 per cent.; bituminous macadam, 8 per cent.; bituminous macadam, 3 per cent.," etc., etc., but these gradients do not appear to synchronise with English practice.

[1] This is placed first on sanitary grounds.

[2] Whilst horses are still employed to drag loads this requirement must stand.

that a properly devised reinforcement with steel wire netting, or bars, greatly strengthens this description of foundation, so that a less thickness is necessary than in the case of ordinary concrete.

The Road Bed.—It is important that the road bearing-bed, or ground on which the concrete is to be placed, should be hard and undisturbed; any soft places should be taken out and filled, and rammed with good hard material, and special care should be taken to remove any vegetable or other organic or perishable matter. Where any openings have been made, or trenches dug, for gas, water pipes, etc., these should be specially strengthened with concrete brought up to the level and contour of the bearing-bed, as such trenches have been known to subside even after some years have passed since they were excavated. The bed, when properly shaped and prepared, should be well rammed, or rolled, and finally, just before the concrete is put into place, the whole surface should be watered.

The Concrete.—The usual method for the construction of the concrete foundation is to prepare the concrete upon boarded platforms, or bankers, in various proportions of Portland cement and aggregate; for instance, four parts of broken stone or ballast are mixed with two parts of sharp, clean sand, and one part of Portland cement. These are turned over twice with shovels whilst dry; water is added out of watering pots very gently, through a rose, while the mass is again turned over with shovels as the water is being added.

This is rather a crude method as the proportions of the aggregate, the cement, and the water are not very accurately gauged, as they are greatly left to chance and the "will" of the workmen.

The author has given suggestions for the drawing up of a more drastic specification for the preparation of concrete in the chapter on "Concrete Roads," which, if followed, would lead to better results.

It is obvious when looking at some of the concrete foundations of paved streets which are under repair, that a large number of them which have thus become "out of repair," have done so by reason of the inferior quality of the concrete foundation, which was evidently unable to withstand the traffic it had to bear.

Liverpool Concrete Foundation.—The system of the construction of such concrete foundations, which pertained in Liverpool when the author was engineer of that city, was of a different character, and may be described as follows:—

The bearing-bed, or "sub-grade," as the American road engineers name it, having been prepared as explained above, and the channels and kerbs fixed in position, a stratum or bed of stones, broken so as to pass all ways through a 3-in. ring, was spread evenly over the ground. These stones were either a hard granite or of some formation of an equally non-absorbent character.

Upon this bed of stones a layer of cement mortar was laid, composed of one part, by measure, of Portland cement, to six parts of fine, sharp, clean gravel, in the method to be described hereafter.

Upon this layer of mortar was placed another layer of broken stone.

Directly the stones were laid in these layers they were thoroughly watered before the cement mortar was added. The upper layer of stones were forced into the interstices of the first layer by the use of flat beaters of wrought-iron, shaped like square shovels, with handles at an angle of about 33°. This process was repeated until the proper level and contour was reached of the surface of the foundation on which the setts were to be paved. This surface was then finished off parallel to the exact camber of the finished paved street.

The foundation, thus prepared, was left until the concrete was sufficiently set, or hardened, to receive the pavement, and this was found to be about ten days at least, according to weather conditions. Unfortunately, as in most cases of street construction, the exigencies of the traffic curtailed this period, and in such cases the only method to meet a shorter time of rest was to make the mortar stronger by increasing the proportion of Portland cement to the aggregate whilst "resting";

after completion, the surface of the concrete was frequently thoroughly watered to assist in the ultimate hardening, and in very hot weather the whole surface was covered over with old cement sacks saturated with water.

The proportions of the "mixtures" used in such concrete were as follows:—

Before Mixing.—Eight parts broken stone; six parts of gravel; one part cement.

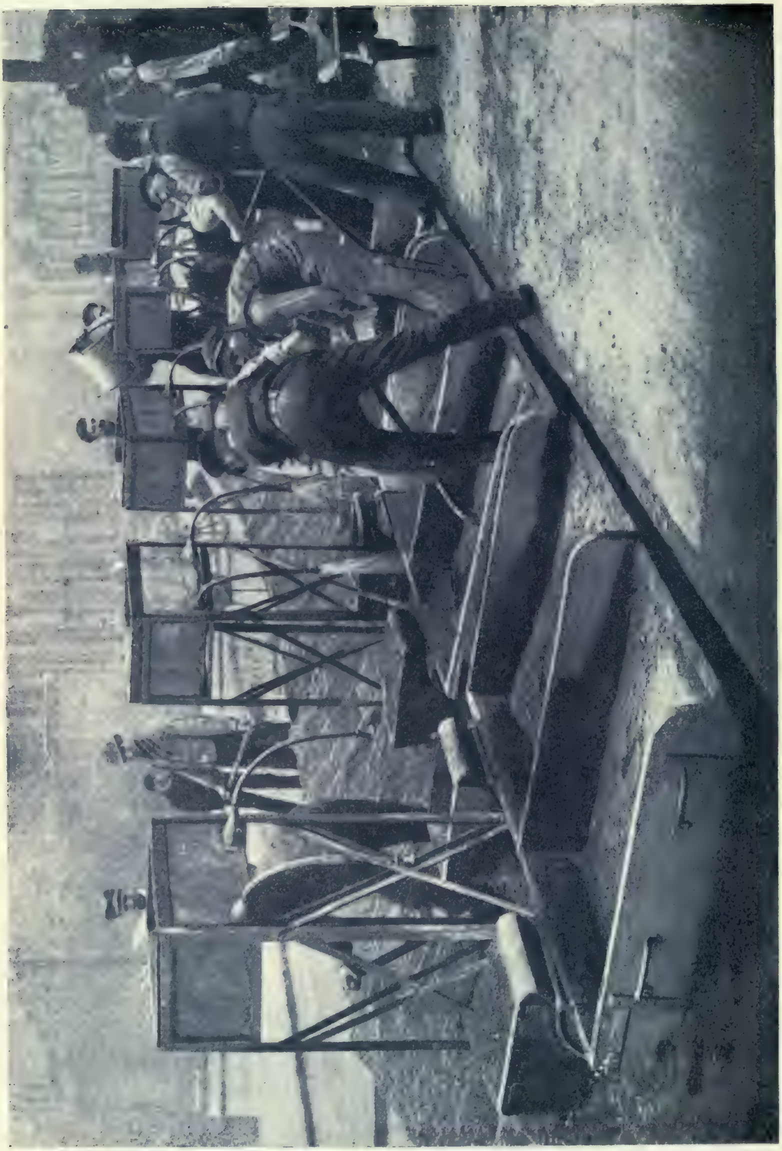
After Mixing.—Broken stone and gravel mixed together, eleven parts; cement, one part; three parts of gravel having been expended in filling the interstices of the stones.

To secure that the cement mortar should contain the proper proportion, an apparatus was used which may shortly be described as follows:—

It consisted of a set of double "mixing boards" or bankers placed on the ground; each compartment was 7 ft. in length by 3 ft. 6 ins. in width, with a back 9 ins. in height, made with 1½-in. deal boards, the bottom being lined with sheet iron. There was a partition in the centre which divided the mixing board into two compartments, each of convenient size for one man to mix his batch of concrete. At the back of each compartment was a tipping box for measuring the gravel or ballast with a capacity of exactly 1 cubic foot, viz. 14 ins. square at the top, 10 ins. square at the bottom, and 12 ins. in depth. It was hinged in such a manner that after being filled the contents could easily be tipped on to the floor of the banker by the man mixing the materials. The cement was measured in light iron bowls and added as will presently be described.

Each banker could be easily carried by men, and any number of bankers could be placed side by side about one foot apart, the water supply being arranged as follows:—

A length of flexible tube was attached at one end to a hydrant on the nearest water main and at the other end to the ball-tap of a sheet-iron regulating cistern containing 18 gallons, fixed on a light angle-iron frame, the bottom of the cistern being about 4 ft. above the level of the ground. This cistern was placed at one end or the other of a series of mixing boards. Opposite to the inlet ball-tap was an outlet pipe of flexible



Liverpool System of "Hand" Concrete Mixing.

tubing, attached to the cistern by brass unions, which conveyed the water to a horizontal wrought-iron pipe 7 ft. long [the same length as the banker], which was supported upon light iron standards placed over the back of each mixing board. Attached to this pipe was a pair of brass, swivel rose-ended pipes with stop-taps, the roses being so arranged as to discharge the water in a gentle spray over the centre of the concrete as it was being turned over on the banker. This arrangement could be extended to any number of mixing boards by connecting the pipes with flexible tubing, as occasion demanded. Another method was to have the cisterns fixed directly behind, and over, the bankers and discharge the water through a flexible hose, fitted with a rose at the discharge end, which sprayed the water on to the concrete in a similar manner.

The illustration (Plate XIII) shows this latter arrangement and the operation as actually being carried out. This operation may be described shortly as follows:—

The mixing boards were placed with their backs to the heap of aggregate, gravel, or ballast, etc.; the cement was stored at one end or the other, also at the back of the mixing boards. One labourer with a mixing shovel was told off to each compartment, another man at the back filled each measuring box with the gravel; the mixer in front then tipped over this box with his shovel; a boy brought the bowl of cement containing exactly one-sixth of a cubic foot, or such other quantity as had been previously decided, and spread it over the gravel; the mixer then turned over the contents of his board until the cement and gravel were thoroughly mixed in a dry condition; he then turned the tap of the rose pipe and allowed the water to flow over the mixture, using his own judgment as to the quantity of water required [varying with weather conditions, the quality of the aggregate, etc.], and quickly again turning the mixture over and over in its wet state. The concrete was then placed in wheel-barrows and conveyed to its destination. It was found that with this apparatus and systematic procedure that one mixer could turn out 90 such mixings in 9 hours which is equal to 6¼ cubic yards.

The method adopted at Liverpool was a distinct advance on the usual rather haphazard methods which even now prevail, but even this method left too much to the workman's individuality. The more modern method for concrete mixing is with special machines as mentioned in the chapter on "Concrete Roads".

Pavements.—With regard to the selection of the material to be used for paving on a concrete foundation, the following are those in principal use:—

(1) Granite or syenite setts.

(2) Setts of softer stone, such as sandstone, gritstone, whinstone, etc.

(3) Wood paving.

(4) Natural rock asphalt.

(5) Durax.

(6) Bricks.

(7) Various artificial blocks.

(1) **Granite Setts.**[1]—There can be no doubt as to the durability of granite or syenite setts as a paving material; this was proved incontestably at Liverpool, where the economy of maintenance was carefully noted. In the year 1872, when granite sett pavements were first introduced into that city, there were about 200 miles of roads and their annual

[1] A definition of granite may be taken as follows:—

A typical granite is a crystalline aggregate of the minerals quartz, felspar, and mica.

Quartz is the most resistant to wear.

Felspar is the next. There are three principal varieties: microcline, orthoclase, and plagioclase; the two first-named are potash felspars, while the last-named is a soda felspar.

Felspar is a mineral of very variable composition, and it has been established that the potash felspars are much more resistant than those which contain soda.

Mica is the least durable mineral in granite, particularly the white variety termed Muscovite, which has a flaky structure capable of being penetrated by moisture. The dark variety is termed biotite, and is generally found in crystals of small or medium grain, fairly evenly distributed.

Qualities of a granite suitable for paving should be:—

(1) Resistance to crushing forces.

(2) Durability.

(3) Non-slipperiness.

(4) Evenness of wear.

(5) Resistance to percussion,

maintenance cost £38,280, the interest and sinking fund was £15,756, or a total cost of £54,036, or £270 a mile. In the year 1894, when I was City Engineer of Liverpool, with 258 miles of roads, the annual maintenance only cost £14,205, the interest and sinking fund £36,917, or a total cost of £51,122, or £198 a mile, showing a saving of £72 a mile, this being entirely due to the extended use of granite setts.

The table on next page, prepared in 1894, also shows very clearly that the life of this class of pavement is longer, and the maintenance far less, than the other description of pavements quoted therein.

Size of Setts.—The proper size and shape of the setts is a matter of considerable importance. For stability, a certain proportion must exist between the depth, length, and breadth, and 7 ins. has been fixed as a sufficient and proper depth for any class of traffic. The width is somewhat controlled by the size of the horses' hoofs, and about 4 ins. is now allowed to be the maximum width. The length is governed principally by the ease of handling of the sett by the pavior, and so that each sett will break joint properly with its neighbour, and not be too long, so as to conform to the contour of the road. Stones, if of too great a length, are apt to ride and tilt. Nine inches may be considered as quite long enough. Taking the question of cost into account—and cost of this description of paving, be it remembered, is considerably affected by weight when carriage of the stone has to be considered—the following sizes of stones may be taken as satisfactory[1] :—

Setts . . .	6¼ ins.	× 3¼ ins.	× 5	ins. to 7 ins. long
,, . . .	7¼ ,,	× 3¼ ,,	× 5	,, ,, 7 ,, ,,
Cubes . . .	3¾ ,,	× 3¾ ,,	× 3¾	,,
,, . . .	4 ,,	× 4 ,,	× 4	,,
Blocks . . .	4 ,,	× 4 ,,	× 6	,, deep
,, . . .	3¼ ,,	× 3¼ ,,	× 6¼	,, ,,

It is of the greatest importance that the setts should be thoroughly square and not taper, and that the dressing should

[1] In Paris, after considerable research into the question, the engineers of the Ponts et Chausées decided that the size of the paving stones, which used formerly to be 9 ins. square, should be 4 ins. wide by 6¼ ins. long by 6¼ ins. deep, the stone that is used being a grit sandstone from the forest of Fontainebleau.

CITY OF LIVERPOOL. TABLE OF COST OF REPAIRS OF STREETS UNDER ASCERTAINED TRAFFIC.

Name of Street.	Description of Pavement.	Traffic per yard width per annum.	Average Cost of Maintenance per annum for five years.	Area in yards.	Average Cost per square yard per annum.	Present Condition of Pavement.	Gradient.
		Tons.	£ s. d.	Sup. yds.	s. d.		
First street . . .	Macadam	69,139	140 8 11	1,792	1 6·81	Indifferent	1 in 22
Second street . . .	,,	110,275	137 18 0	1,837	1 6·01	,,	1 ,, 18
Third street (paved 1885) .	Impervious setts	67,315	Nil.	1,573	Nil.	Very good	1 ,, 22
Fourth street (paved 1885)	,,	37,175	,,	1,327	,,	,,	1 ,, 18
Fifth street (paved 1885) .	,,	42,000	,,	7,735	,,	Perfect	1 ,, 500
Sixth street (paved 1877) .	,,	149,000	0 3 11	3,414	0 0·013	Very fair	1 ,, 56
Seventh street (paved 1877)	Henson's wood pavement	100,000	67 17 3	1,310	1 0·43	Much worn	1 ,, 56
Eighth street (first paved 1874)	Improved wood pavement	94,000	219 6 8	4,250	1 0·386	,,	1 ,, 33

be most carefully carried out, and the deviation from the specified size should in no case be allowed to exceed ¼ in. in depth and breadth respectively, and there ought not to be a difference of more than ½ in. between the broad and thin ends of the setts.

The specific gravity of the stone of which the setts are composed is also of some importance as governing the cost, as the lighter setts will, of course, cover a larger area of pavement. For instance, if 500 square yards of paving require 151 tons of setts with a specific gravity of 2·60, and assuming the price at 25s. a ton, the cost would be £188 15s., but if the specific gravity had been 2·90 it would take 168 tons of setts, and if the price of these setts had been 24s. a ton the cost would have been £201 12s., so that there would be a saving in adopting the higher priced stones, provided their durability had been equal.[1]

Various Specifications.—The following examples are given of various "specifications" under which tenders are invited for granite setts by some large cities in England. The names of these cities are purposely omitted, as some of the specifications are by no means perfection :—

(*a*) "The setts to be supplied shall be equal in quality as regards toughness and rate of wear under traffic to the samples submitted by the contractors, and they shall be properly squared. The setts shall be accurately gauged, and this will be tested by calliper, as is customary in the City Engineer's Department, previous to accepting delivery. The maximum deviation from the specified size of the setts shall be ¼ in. in depth and breadth respectively. Setts, where there is a difference of more than a quarter of an inch between the broad and thin ends, will not be accepted.

"Where setts are ordered to be specially dressed they shall be equal in quality as regards toughness and rate of wear under traffic to the sample submitted by the contractor, and they shall be properly squared. The setts shall be ac-

[1] *Vide* "Street Pavements," a paper read before the Liverpool Engineering Society, 14th February, 1904, by Mr. James Morgan, Assoc.M.Inst.C.E.

curately gauged, and this will be tested by calliper, as is customary in the City Engineer's Department, previous to accepting delivery. The deviation from the specified breadth of the setts in any one cargo shall not exceed $\frac{1}{4}$ in. between the largest and smallest setts in that cargo. The depth must not deviate more than $\frac{1}{8}$ in. from the specified size."

The above specification is one of the most complete and detailed in character, as will be seen by a perusal of some of those which follow :—

(*b*) "The setts to be dressed square top and bottom and to be equal in every respect to the samples submitted for your inspection.

3-in. by 6-in. granite setts, i.e. not less than 3 ins. nor more than $3\frac{1}{2}$ ins. wide, 6 ins. to 8 ins. long and 6 ins. deep.

4-in. by 6-in. granite setts, i.e. not less than $3\frac{3}{4}$ ins. nor more than $4\frac{1}{4}$ ins. wide, 6 ins. to 8 ins. long and 6 ins. deep.

4-in. by 5-in. granite setts, i.e. not less than $3\frac{3}{4}$ ins. nor more than $4\frac{1}{4}$ ins. wide, 6 ins. to 8 ins. long and 5 ins. deep.

4-in. granite cubes."

The specification which follows is particularly meagre in its details :—

(*c*) "The size of the setts to be 3 ins. to $3\frac{1}{2}$ ins. wide, 5 ins. to 7 ins. long and 6 ins. deep.

"The contractor is to forward, along with his tender, a sample of the setts quoted for, and the setts are to be supplied in every respect equal in quality, and similarly dressed to the sample."

The following is somewhat better :—

(*d*) "Each sett shall be properly dressed and squared on all its faces, shall be level on the top and bed, and have sides and ends parallel and square. Setts of each class shall be truly gauged. No variation in width greater than $\frac{1}{4}$ in. over or under the sizes specified on orders will be allowed. All setts must be free from cracks and flaws. Setts with bulges or hollows will not be accepted."

The above specification does not specify the sizes of the setts, and it must be presumed that this information is supplied to the contractor with the specification.

(*e*) "The setts and cubes shall be made from hard, sound stone of regular and even quality, and equal to sample; they shall be properly dressed and squared to true and regular shape and gauge; the 6-in. by 3¼-in. setts shall be from 5 to 10 ins. in length, and where any sett or cube varies more than ¼ in. from the specified size, or varies more than ½ in. in gauge or measurement on the same face or side, the same will be rejected."

The following specification appears to be the only one which specifies any description of "test" that is to be made of the setts for crushing or wearing qualities:—

(*f*) "*Granite Setts.*—The setts shall be of the best quality of non-slippery granite, free from beds, veins, flaws, or soft rock, and be properly squared, so that no part of a sett shall be more than ¼ in. within or without the cube size given in the schedule attached hereto.

"No sett will be accepted under this contract that will not withstand a crushing strain of 2,400 tons per square foot."

None of the above specifications are very complete, and the author now gives some suggestions for the preparation of a suitable specification:—

(1) The quality of the granite should be described, or a choice of quarries should be given.

(2) The dimensions of the various sizes of setts to be supplied should be distinctly given.

(3) The requirements as to the hewing or cutting of the setts should be given, such as rectangular in shape, sharp arrises, smooth surfaces, so as to allow fairly close jointing, and other particulars.

(4) The specific gravity of the granite should be demanded, and the results of any tests for crushing, durability under traffic, etc.

(5) It is well to refer to a sample to which contractors should quote,

(6) The period for delivery of the setts should also be specified.

(7) Power to reject setts which do not comply with specification should be retained by the engineer.

Before passing on to deal with some of the softer class of stones employed for street paving, reference must be made to what are known as—

"Nidged" Granite Setts.[1]—These setts were introduced in Glasgow, a few years ago, by Mr. Thomas Nisbet, A.M.Inst.C.E., the City Engineer and Master of Works, and may be shortly described as follows:—

Each sett is axed on the top, jointed on the sides and ends, dressed on the bed, and is level on the top and bed, the sides and ends being parallel and square. The axing, jointing, and dressing to be equal to a sample to be seen at the office of Public Works, Glasgow. The setts of each class must be truly gauged. No variation in width or depth greater than ¼ in. over or under the sizes specified are allowed. All the setts must be free from cracks and flaws. Setts with bulges or hollows will not be accepted.

The sizes of the setts are as follows:—

4	ins.	wide	6	ins.	deep.
4	"	"	7	"	"
5	"	"	6	"	"
5	"	"	7	"	"

Of the above sizes, the sett most generally used in Glasgow is 5 ins. wide by 6 ins. deep, in lengths from 8 ins. to 12 ins.

Such setts as the above-described "nidged" setts are a great improvement on the ordinary hewn setts which have been used for so many years past, but even a still greater improvement in this direction is that which follows, viz.:—

"Grey Royal Granite Setts."—This is the trade name given to a granite sett, or rather "block," dressed and laid in a special manner which requires more than a passing notice, as

[1] A "nidged" stone, or sett, means a stone which has been dressed with a sharp-pointed pick or hammer, instead of being merely hewn,

it appears to be a development in the methods which have pertained for so many years past in this description of street paving. The granite from which "Grey Royal" blocks are made is selected as being of a hard and close grain, but of such a gritty texture that it does not "polish" under the traffic or become slippery. It consequently never requires to be "sanded," or "gritted," which is the case with most of the granite sett pavements, a practice which, whilst temporarily relieving the slipperiness, only adds a material to the surface which assists in polishing it and making it more slippery.

A convenient size for these blocks has been found to be 5 ins. in width, and either 4 ins. or 5 ins. deep, according to the intensity of the traffic, the lengths varying between 6 ins. and 10 ins. As these blocks are carefully dressed and truly squared on all faces, with regular surfaces and sharp arrises, they can be laid with very narrow joints, a very important point in their favour, and impossible to be effected with ordinary rough hewn granite setts.

In laying these blocks upon the properly constructed concrete foundation a different method is followed to that practised in laying the ordinary sett pavements.

The blocks are laid on a very thin cushion bed of fine sand, and, owing to their equal depth, no ramming is required, the pavior merely placing each block in position, as close to its neighbour as it will go, and then "tamping" it with his hammer to level it in place. Instead of the usual racking and grouting required for ordinary sett paving, the narrow joints are merely filled with a hot bituminous liquid, from the narrow spout of a can, to within about an inch of the top of the finished surface of the road. The joints are then filled up to the surface with a liquid grouting of neat Portland cement. This is done to seal up the bituminous grouting and to further protect the arrises of the blocks. With ordinary sett paving the joints are always the weak spots, the arrises wear off, become rounded, and a "jolty" or "bumpy" road is the consequence.

It is claimed for this description of granite paving that it is almost as noiseless as a street paved with wood blocks, that it is non-slippery in all conditions of the weather, and, consequently, never requires sanding or gritting like wood and other forms of paving, that it is smooth for the traffic, quite impervious, and is easily cleansed.

Examples of this description of pavement can be seen at the junction of Tottenham Court Road with Oxford Street and Charing Cross Road, where the traffic is exceptionally heavy and trying. From a census of the traffic taken a short time ago it appeared that there was a daily traffic of 25,000 vehicles a day, of which about 5,000 were motor omnibuses. Croydon, where it was first laid about twelve years ago, has a considerable length of streets on this system, and it has also been used in Belfast, Nottingham, Ilford, and elsewhere.

No doubt the Great War stopped progress in this direction in the same manner as other works were affected, but it is evident that this is a step in the right direction for the improvement of the pavement in streets subject to heavy traffic, as the method adopted appears to have advantages over the usual *modus operandi*, not the least of the advantages of this description of pavement being the absence of wide joints and the even depth of the blocks, causing a smooth and almost noiseless pavement.

Having thus far dealt with the subject of granite sett paving, the author will now proceed to give a few particulars as to the use of—

(2) **Gritstone Setts.**—The softer stones, such as sandstone, gritstone, etc., are generally only used for street paving purposes in the localities where quarries of this description of stone exist. They are naturally not suitable for paving purposes where the traffic is heavy in character or considerable in number of vehicles. If, however, the stone is selected from a "reputed" quarry, such setts, or blocks, are well suited for streets of steep gradients, as their texture gives a sure footing for horses, and they are much used on this account in Yorkshire, Lancashire, and other districts.

Setts or blocks made of such stones should, however, be larger than those specified for granite setts, in order to give them a wider bed and more strength to resist crushing, and also in view of their non-slippery character; it is not necessary to have so many joints as is the case with granite or other hard and somewhat slippery stone.

The sizes specified, therefore, are generally from 8 ins. to 10 ins. in depth; from 6 ins. to 8 ins. in width, and from 7 ins. to 10 ins. in length.

Where the traffic is of a "heavy" character the blocks should be laid and grouted in a somewhat similar manner to that described for laying granite setts, but, where the traffic is light, the blocks may be laid on a well-rolled and consolidated foundation on the "Telford" system, or on a thoroughly consolidated foundation of slag, foundry ashes, or clinker, a practice which is largely adopted in towns or cities where these materials are plentiful and available. As an instance of the usefulness of this description of block as a paving material, it may be noted that in Hill Street, Birmingham, Yorkshire gritstone setts have been laid on a gradient of 1 in 11! about the only class of pavement that could be laid on such an incline. Owing to the severe traffic to which they are subjected they were bedded on a Portland cement concrete foundation, and the joints were grouted with a grout composed of Portland cement and sand. This paving was carried out eleven years ago, and notwithstanding the considerable traffic it is reported to be still in good condition.

It is evident that setts, or blocks, of some of the "softer" stones will still have a place in the category of street paving materials.

Only a few words are necessary to describe "Whinstone Chip Pavement," as it is a class of pavement now very rarely used:—

Whinstone Chip Pavement.—This is sometimes called "Random Stone Paving," and is very nearly akin to an ordinary water-bound macadam road with a sort of mosaic surface. A short description of this class of "pavement" is as follows:—

The ground is excavated in the usual manner and a hard pitched foundation on the Telford system is constructed and consolidated. A bed of screened engine ashes 3 ins. deep is then laid on this foundation.

Whinstone stone, spalls, or chips, are then bedded in these ashes with their larger surfaces upwards and beaten into the ashes by heavy wooden rammers weighing about 40 lbs. The top surfaces of these spalls or chips are generally specified as not to exceed 20 sq. ins., or to be less than 8 sq. ins., as the limits between these two sizes were found to give the best results. No grouting is given to these "chips," the joints being filled by brushing engine ashes or cinders over the surface.

At one time many back streets, and streets of not much importance, were "paved" in this way in some of our northern towns, but it is hoped that this description of pavement has been relegated to the limbo of the past, as it is obvious that such a so-called pavement is insanitary, unstable, and, although it may be cheap in first construction, it must be costly to maintain in proportion to its small value as a street pavement.

A description has only been given of chip pavement as a sample of this form of construction, of which there are others, to show what has been done in this way, even lately, and to demonstrate the fallacy, or even worse, of constructing streets in this manner. Such a method has no place in the category of modern street or road construction.

Having thus far dealt with granite sett paving and the softer stones, the author will next deal with the third material given in his list on p. 214, viz. that of—

(3) **Wood Paving.**—The increased use of wood blocks as a paving material has been remarkable during the last forty years, or more, and the various criticisms directed against it have gradually disappeared.

Early Criticisms.—It was alleged, for instance, that wood absorbed the dung-polluted water from the streets and was consequently insanitary, that it was slippery, that it could not be easily cleansed, that it would soon wear out under heavy traffic, that it would absorb moisture and be bound to swell or expand, and thus push the kerbs and footpaths out of place, and many other allegations, including one that now seems absurd, but which was seriously suggested, viz. that in case of a fire to adjoining premises the conflagration would spread along the streets paved with wood with disastrous effects! None of these early allegations have been substantiated, and wood blocks are now proving to be one of the most popular materials for street paving, not only in London, but all over the civilised world.

First Attempts.—It was said that the first wood pavement to be laid in this country was in the Old Bailey, in 1839, but as it merely consisted of large pine blocks placed direct on the sub-soil, it very soon rotted and failed.

But this failure could not have deterred progress, for in the year 1843, Mr. Charles Cochrane, the President of the Association for the Promotion of Improved Street Paving, etc., in a paper which he read before the Institution of Civil Engineers on "The State of the Streets of the Metropolis," said that there existed at that date 100,000 square yards of wood pavement,[1] and he approved of it as the best material hitherto used, "both as regards its general economy and durability, as well as its facility of traction, and more especially its extreme cleanliness". A striking testimonial to wood paving, as a Mr. Edward Lomas, two years previously, had condemned wood pavement as slippery, and recommended granite pavement for horses, with wood tram-tracks for the wheels of vehicles!

Descriptions of Wood Employed.—Since then there has been a steady evolution in the progress of wood paving. Many descriptions of wood have been tried, such as ash, beech, elm, oak, and "pitch pine" of all sorts, as well as woods from Australia, such as Karri, Jarrah, and other eucalyptus, or blue gum types, which were known as "hard wood". These have

[1] *Vide* "Minutes of Proceedings of the Institution of Civil Engineers," vol. i., p. 131.

been partially abandoned for various reasons which are too lengthy to enter upon.[1] Experience has shown, however, that woods of the *Pinus Sylvestris* family are the best for the purpose. These are called "soft woods," and are known as Baltic fir, Baltic red deal, Scotch fir, Scotch pine, Swedish yellow deal, and other trade names. Such wood has been found to be of the right "grain" and substance to meet the requirements of wood paving, and if properly "treated," as will be explained later, and laid on a sound concrete foundation, will stand for many years against a heavy and concentrated traffic.

Resilient Nature of Wood.—In the earlier days of this description of paving it was rather naturally assumed that a comparatively soft material, such as wood, could not have the same durability as a granite sett or other hard material, but it is claimed for wood that it is resilient, and partly elastic, and that consequently the shocks it receives from the traffic are distributed and absorbed in such a manner as to prevent damage either to the block or to the rigid concrete foundation underneath.

This claim appears to be perfectly sound and accounts for the fact that a soft material like wood should be able to stand the traffic at all.

Introduction of Self-propelled Vehicles.—It is interesting also to find that the introduction of rubber-tyred, self-propelled vehicles has been in favour of wood pavement, and that the wear is less than that under the former horse-drawn, iron-tyred vehicles. Even so long ago as the year 1908, the City Engineer of Westminster reported, "On wood-paved roads the traffic of motor omnibuses, fitted with rubber tyres, is not more detri-

[1] One of the reasons for the failure of the "hard woods" was their shrinkage and also the tendency for the arrises to round off. To meet this difficulty a hard-wood sectional block called the "Acme" block was introduced which overcame these difficulties. These blocks are 9 ins. long, 3 ins. wide, and 3½ ins. deep, made up of small sections dovetailed together on the underside by tongues let in obliquely. The blocks are laid direct on the concrete and the joints very carefully filled in with hot pitch grout, and the result makes an excellent pavement free from shrinkage or uneven wear.

mental than the ordinary horse omnibus".[1] Recent observations seem to have confirmed this view.

Average Life.—As to the average life of the blocks of a wood-paved street, of course much depends upon locality, class, and intensity of the traffic, the strength and quality of the foundation, a very important factor, and the amount of attention it receives in the way of casual and slight repairs as they become necessary. In every description of street or road covering attention is necessary, and if small necessary repairs are not attended to at once, they become worse and worse until the whole surface has to be removed and reinstated much earlier than would have been necessary if these repairs had been at once effected.

From a published report of the date at which certain streets were paved with wood in London, and the date when replacing became necessary, the life seems to have ranged from as long as 20 years in two cases, to the shortest, viz. one of 10 years; the average life over the whole of the twenty examples given amounting to 14·3 years. The Local Government Board 15 years ago granted a term of 7 years[2] for repayment of money borrowed for this description of paving; they now grant a term of 10 years, showing that experience has proved that this description of paving possesses a longer life than was at one time anticipated.

Quality of Wood.—With regard to the necessary quality of the wood, it is usually specified to be thoroughly sound, free from all traces of sap,[3] close grained, uniform in quality, and free from knots or shakes. It is not the modern practice to specify "well-seasoned wood," as it appears from experience that the wood is better for having a little "life" in it.

The American practice is to also specify the minimum number of annual rings to be permitted in a block, some specifications permitting 5 or 6 per linear in., and others not less than 8 or 9. The object of this does not appear to be

[1] *Vide* the "Fifth Annual Report of the Metropolitan Committee on Materials and Means of Paving the Streets of London," p. 9.

[2] At one time it was only five years.

[3] The rather vexed question of "sap" will be dealt with later, *see* p. 234.

very clear, as trees will make these rings with varying conditions of the seasons, and also whether the soil is very damp or abnormally dry, so that as a guide to the age of the tree it is not altogether reliable. Neither do American engineers appear to limit the amount of sap wood, as it is stated that recent experience seems to indicate that there is no noticeable difference in wear between heart-wood and sap-wood.[1]

Dimensions of Blocks.—With regard to the dimensions of the blocks, they were formerly specified to be not less than 6 ins. or more than 12 ins. in length, by 3 ins. in width, and 6 ins. in depth. The more modern practice, gained by experience, is to have the block not less than 6 ins. nor more than 9 ins. in length, as a longer block does not "fit in" with the camber of the road, and also may possibly "ride" on any inequality of the surface of the concrete. The depth also has been reduced from 6 ins. to 5 ins., 4 ins., and in some cases even to 3 ins. The "life" of any description of pavement does not mean its wear to destruction, but only to the point where the increasing unevenness of the surface makes it imperative to renew the whole pavement. Thus it is evident that to specify the use of a block of say 6 ins. in depth, is an extravagance in wood, cartage, etc., for it has been found that such blocks have had to be taken up when only about 2 ins. of their top surface had been worn away by the traffic, and the remainder of the block remained intact. Three inches, however, should be the *minimum* depth, as otherwise the block would have an insufficient support from its neighbours.

Impregnation or Treatment of the Blocks.—In the earlier days of the use of wood blocks they were laid in their natural state, untreated in any way, but it was soon discovered that decay set in, and various "preservatives" were introduced, such as:—

(1) Burnetising .	. Chloride of zinc being used.
(2) Kyanising .	. Corrosive sublimate being used.
(3) Boucherising .	. Sulphate of copper ,, ,,
(4) Renwickising .	. Boiling in coal tar.
(5) Seelyising .	. Creosoting after boiling the blocks.
(6) Bethelising .	. Creosote heated to 200° F.

[1] For further information on these points, *vide* "A Treatise on Roads and Pavements," by Ira Osborn Baker, C.E., D.Eng., 3rd Edition, p. 605.

The latter, with modifications and improvements, still survives, the others having passed out of favour for various reasons.

The impregnation of the block is not only necessary for its preservation, but also to prevent the absorption of water and to act as an "antiseptic". It has been stated that this power of absorption by wood varies from 9·37 per cent. to as high as 174·86 per cent. in very dry wood. In its ordinary condition it is stated to vary between 4·36 per cent. to 150·64 per cent. The quantity of water contained in wood, in its natural state, varies from 4·61 per cent. to 13·56 per cent.[1]

Thus it will be seen that it is imperative to withdraw all the moisture out of the block so far as possible, and also the bulk of the air, before any process of chemical impregnation can take place.

Modern Method of Impregnation.—The following is a short description of the method now usually adopted for effecting this process of impregnation:—

The blocks, having been sawn from the planks of the required dimensions, are placed in a closed cylinder which is then subjected to a vacuum for about an hour, thus liberating all moisture and a great deal of the air, to make room for the preservative.[2] Then, while the cylinder is still under a vacuum, the preservative is admitted until the cylinder is completely full. Pressure is then applied by pumping more preservative into the cylinder, and this pressure is maintained for about two hours at about 120 lbs. per square inch, thus forcing the preservative into the fibre of the wood.

The preservative now almost generally used is creosote oil containing about 5 per cent. of "tar acid". The oil is previously heated to such a point as will thoroughly liquefy and attenuate it. The question of the amount of preservative which should be forced into the blocks has been subject to some discussion, but it is now generally held that about 10 lbs.

[1] *Vide* "Minutes of Proceedings of the Institution of Civil Engineers," vol. lvi., p. 300.

[2] In America it is customary to admit steam into the cylinder *before* creating the vacuum, as it is contended that this softens, or liquefies the sap, leaving more room for the preservative.

of creosote oil to each cubic foot of wood is the right quantity. Too little would necessarily be insufficient to penetrate to near the centre of the block, whereas too much would lead to the "bleeding" of the blocks after they were laid, which is of course objectionable and to be avoided. The blocks should be used as soon as possible after treatment, as otherwise they are apt to "dry out" if stacked for any length of time. In order to see if the blocks have received sufficient treatment it is customary to select blocks, at random, out of the batch, saw them in half and observe if the creosote has reached the centre or how far into the block; if it is insufficient the process of impregnation must be repeated. Another simple method is to weigh a "parcel" of blocks of say 50 or 100 before treatment and to weigh the same "parcel" after treatment, the difference in the weight being thus the ascertained weight of the oil which the blocks contain. Before weighing the treated blocks they should be wiped over with a rag or waste to remove the extraneous oil.

Foundation.—Wood blocks should always be paved on a sound and properly constructed concrete foundation of sufficient thickness to withstand the heaviest traffic which they are likely to be called upon to bear. This concrete foundation should be constructed in the manner already described and not in the haphazard manner in which it has frequently in the past been unfortunately executed. Hitherto there does not seem to have been much discretion used in the depth to which the concrete foundation should be constructed, and a standard depth of 6 ins. appears to have been adopted. Since the advent of self-propelled vehicles, of increasing weights and speed, more discretion has been used as it has been found that this thickness is in many cases insufficient, and that unless the concrete is "reinforced," it is necessary to increase the depth of the foundation to at least 9 ins. and in some cases to even more. It is evident, on examining some of the wood paving in London and elsewhere, which has become badly out of repair, that it is due, not so much to the wear of the blocks, but to the inadequacy of the foundation, which was neither thick enough or well made enough to withstand the weight of the traffic. Unfortunately also, owing to the exigencies of traffic, sufficient time has not been allowed to give the concrete an opportunity of "setting". The incessant vibration of the traffic prevents the setting which in consequence never properly takes place.

Use of Old Concrete Removed.—Where an increased depth of foundation is required to a wood pavement which is to be relaid, it appears very wasteful that the old concrete should have to be carted away to the "spoil heap," as this material, if properly crushed, should make an excellent aggregate for the new concrete.

The author understands that this has recently been done in a case of this kind, where a street, subjected to very heavy traffic, had to be relaid with wood blocks upon a thicker foundation. The old concrete was crushed and a good sandy ballast added in the proportion of 3 of crushed concrete to 2 of ballast, and 6 parts of this mixture to 1 part of Portland cement made an exceedingly good concrete which admirably answered the purpose.

Early Methods of Laying.—In the earlier days of wood paving the blocks were laid on a "cushion bed" of fine sand, with joints of about $\frac{1}{4}$ in. in width, which were afterwards "racked" with sharp gravel, and grouted with either cement or a bituminous liquid grouting. It was claimed for the sand "cushion bed" that it absorbed the grouting and prevented the possible upheaval of the blocks, and also formed a "cushion" between the wood and the rigid concrete foundation, and that this assisted in distributing the concussion of the traffic. For the "racking" it was claimed that it entered into the sides of the blocks and thus prevented, in some measure, the effects of the swelling and expansion of the blocks due to moisture, and prevented the upheaval and forcing away of the kerbs at the sides of the carriage ways, which in earlier days sometimes occurred. But it was found by experience that the $\frac{1}{4}$-in. joint was too wide and that it allowed the arrises, or edges, of the blocks to chip and wear off under the traffic, thus soon causing a rough or corduroy road, and was consequently abandoned in favour of no joint at all! The blocks for a considerable period after this were laid as close together as they could be pressed; any crevices or minute cavities between the blocks being afterwards filled with a thin hot bituminous liquid which was squeegeed into them, but this method did not give sufficient "play" for expansion, the absence of joints caused the surface to be somewhat slippery, and the practice was abandoned for a more modern method which will be explained later.

The Cushion Bed.—The cushion bed of sand under the blocks has also been abandoned, as it allowed individual blocks to sink, thus not only causing an uneven surface, but also destroying the adhesive joint between the blocks. The practice of putting a cushion bed still pertains in America, where the blocks are bedded on a layer of sand from 1 to 2 ins. in depth, or a "bedding course" is provided of dry cement and sand about ½ in. thick. In both cases the blocks are well rolled after being laid, in order to properly bed them before they are grouted.

Bituminous Bedding.—Another method, largely practised in America, and occasionally in this country, is to spread melted coal-tar pitch, at a temperature of about 280° F. to a depth of about ⅛ in. over the whole surface of the concrete, the blocks being immediately laid on the melted pitch before it can solidify. The advantages claimed for this latter process are that it holds the blocks in place as the pitch acts as a strong adhesive between the block and the concrete, and also that the pitch completely seals the bottom of the block against any moisture that may reach the top of the concrete foundation. The advantage of the adhesion is doubtful, for it is stated that, in pulling up the blocks laid in this manner, they adhere so firmly to the concrete that pieces of the concrete come away with the block. This must be extremely "tiresome" and expensive when the blocks have to be removed in order to place new blocks on the existing concrete. It is also extremely doubtful if there is ever much wet on the surface of the concrete in sufficient quantity to be detrimental to the blocks.

Modern Practice.—The most modern and now almost universal British practice is to place the blocks direct on the finished surface of the concrete, which has of course been previously brought up to the proper levels and contour, without any intervening material of any kind between the block and the concrete. This concrete should, if possible, have been allowed a sufficient time to properly set and consolidate. As a rule, only about five or six days can be allowed for this rest owing to traffic necessities, which is really insufficient for the purpose. On this finished, and it is to be hoped, matured concrete, the blocks are then laid in the following manner:—

Strips of wood, or laths, about $\frac{1}{10}$ of an in. or $\frac{1}{12}$ of an in. in width and 1 in. in depth are placed between each row of blocks as they are laid; these are left in and are afterwards grouted in with the blocks. This grout usually consists of a hot liquid bituminous mixture which is poured over the blocks and carefully squeegeed into the joints until they are filled up to within about $\frac{1}{2}$ in. of the surface; this $\frac{1}{2}$ in. is afterwards filled to the finished level of the road with a sand and Portland cement grouting. A liberal coating of suitable gravel or ballast is then spread over the whole surface of the wood paving and the street is then ready for the traffic.

Expansion Joints.—In laying the blocks, provision must of course be made for expansion, as even blocks that have been thoroughly impregnated are liable to swell. An expansion joint or open cavity is therefore left on each side of the carriage way running close to and parallel with the whole length of the kerbs. These expansion joints are usually about $1\frac{1}{2}$ ins. in width and are filled up with clay or some other compressible material so as to "take up" any movement of the blocks, due to their absorption of water, and consequent swelling.

Hints for a Specification.—It would not be possible to standardise a specification for wood paving blocks, but the following suggestions are given as a basis on which a specification might be formed subject to the particular requirements of the case:—

The Timber.—A good timber for the purpose would be selected Swedish or White Sea yellow pine; the planks should be 3 ins. thick, not less than 7 ins. or more than 9 ins. wide, of the quality known in the trade as "Gefle" or "Soderham," fourth yellow, or of some equal timber.[1] It should be of a heavy close-grained nature, free from discoloured sap-wood.[2]

The Blocks.—The blocks must be sawn true in shape and size, and of the exact dimensions specified. No block must vary from the depth specified, but a variation of $\frac{1}{8}$ of an in. in the width will be allowed, but no block under 3 ins. wide will be accepted. The blocks must be free from large, loose, or dead knots, wavy edges, warps, shakes, or other defects. One surface at least of every block must be free from any knots, and no block shall contain more than 20 per cent. of sap-wood. Before the blocks are creosoted they should be inspected by a competent and trustworthy person to see if the above conditions have been complied with. The blocks must then be creosoted under the "Bethell process," viz. under pressure. The creosote to be a distillate from gas tar known as creosote oil.

Material for Impregnation.—Engineers are somewhat at variance as to the best "composition" of creosote oil for this purpose, but the following particulars of a "specification," prepared by the American Wood Preserves Association, are

[1] Spruce or "white-wood" should not be used.

[2] There has been from time to time some controversy, or difference of opinion, as to whether the presence of sap is detrimental, or not, in wood that is to be used for paving blocks. From a theoretical point of view it might be considered desirable to select blocks entirely free from sap-wood, but this would greatly increase the cost, even if it were possible to secure a sufficient quantity of such timber. It has been found on examining old creosoted paving blocks with considerable sap-wood in them, that they do not in most cases show any more wear or deterioration than the adjoining heart-wood. This may be due to the fact that sap-wood is capable of absorbing more creosote than heart-wood, and in fact does so. If, however, the sap-wood had already been in a state of putrefaction before being treated, with a consequent breaking down of the cellular structure of the wood, the creosote could not replace this cellular structure, it can only arrest or prevent decay. When, therefore, a wood block shows a blue discoloration it is an indication that it has passed beyond the stage at which impregnation will arrest the decay, and such a block should be rejected as unfit to bear the strain of traffic.

given, as it has been approved by practically all of the national engineering societies interested in wood preservation :—

(1) The oil shall be a distillate of coal-gas tar or coke-oven tar.

(2) It shall not contain more than 3 per cent. of water.

(3) It shall not contain more than 0·5 per cent. of matter insoluble in benzol.

(4) The specific gravity of the oil at 38° C. compared with water at 15·5° C. shall be not less than 1·06.

(5) The distillate, based on water-free oil, shall be within the following limits: up to 210° C. not more than 5 per cent., and up to 235° C. not more than 15 per cent.

(6) The specific gravity of the fraction between 235° and 315° C. shall be not less than 1·03 at 38° C. compared with water at 15·5° C. The specific gravity of the fraction between 315° and 355° C. shall be not less than 1·10 at 38° C. compared with water at 15·5 per cent.

(7) The residue above 355° C., if it exceeds 10 per cent., shall have a float-test of not more than 50 seconds at 70° C.

(8) The oil shall yield not more than 2 per cent. coke residue.

As a comparison with the above analysis the following is given as emanating from an English engineer :—

The creosote is to be pure tar distillate of the very best quality creosote, free from all impurities, and on analysis to give the following results :—

(1) To be entirely liquid at a temperature of 85° F., and to remain so on cooling to 75° F.

(2) To contain not less than 25 per cent. of constituents that do not distil over a temperature of 600° F.

(3) If any water be present, the total quantity yielded by distillation not to exceed 3 per cent.

(4) To yield a solution of caustic soda not less than 8 per cent. [by volume] of tar acids.[1]

(5) The specific gravity of 60° F. to range between 1·040 and 1·080, water being 1·000.

[1] Oil giving over 6 per cent. is more volatile and, therefore, is not so useful as it would evaporate in time.

The question of the "composition" of the creosote oil having been settled, the blocks must be impregnated with it in the following manner:—

Process of Impregnation.—They are placed in a large cylinder capable of holding, say, 15,000 blocks in one batch. A vacuum is then created in the cylinder equivalent to about 20 ins. of mercury. The creosote oil, previously heated to a temperature of at least 150° F., is then admitted into the cylinder and kept up at a pressure as described on p. 229. The quantity of creosote oil forced into the blocks shall be 10 lbs. weight of oil to every cubic foot of wood. This can be ascertained by weighing 100 blocks before being put into the cylinder, and then after they are impregnated, they must be carefully wiped and then weighed. The difference between their weight before treatment and their weight afterwards will give the weight of the oil absorbed.

Engineer's Powers of Inspection.—The engineer should also insert some clause in his specification giving him, or his authorised agent or agents, authority to enter the contractor's premises at any time, in order to see the processes of cutting and creosoting the blocks, and of rejecting those which are found to be unsuitable. The engineer should also have power to take samples of the creosote oil for analysis at any time, and should it be found that it is not satisfactory the whole of the blocks creosoted with such oil may be rejected. It is very necessary that the cutting and creosoting of the blocks should be done on the same premises for obvious reasons; a dry block might twist, or rasp, or even crack if allowed to remain untreated for even a short time. Finally, it would be well if the engineer reserved the right also, notwithstanding his representatives' previous examination of the blocks, to reject any blocks on the street if, after examination, they were not, in his opinion, in accordance with his specification.

The method of laying the blocks has been previously described and need not be repeated.

Merits of Wood as a Pavement.—When we see the very large preponderance of wood paving in London and other cities and towns in this country, it is evident that this description of construction is exceedingly popular, and that as a modern pavement it has many advantages, the following being some which are claimed for it:—

(1) That it meets all the requirements of modern traffic.

(2) That it is less slippery, under all conditions of weather, than most other descriptions of paving.

(3) That it is noiseless.

(4) That it is easily cleansed.

(5) That it offers a good foothold for horses, and at the same time is popular with motorists.

(6) That by reason of the antiseptic qualities in the creosote oil, with which it is impregnated, it is a sanitary pavement.

(7) That it can be laid on fairly steep gradients.

(8) That owing to its absorption of the shocks of the traffic it is able to withstand heavy and concentrated traffic.

(9) That it is resilient and slightly "elastic," which is favourable to the vehicles passing over it.

(10) That if properly constructed it does not become either corrugated or wavy.

In wood paving we seem to have reached the *ne plus ultra* of road construction. I have seen cobble stones give way to water-bound macadam, which in turn was displaced for the old fashioned granite setts, and this was finally removed to make place for wood paving. Whether in the evolution of road making this description of paving will disappear in favour of more better material remains to be seen, but so far, there appears to be every indication that wood paving will hold its own for some years to come, as the most suitable pavement for streets in the cities and towns of this country.

Having dealt at some length with the subject of wood paving, the author now turns to the next subject, that of—

(4) **Natural Rock Asphalt.**—The unfortunate changes in the nomenclature of asphalt and bitumen have led to some confusion with regard to asphalt, one of the chief reasons being that American road engineers have had but little experience with natural rock asphalt roads, as the most suitable rock for

this purpose is only to be found in Europe. Curiously enough, however, with nearly all the artificial asphalt, or bituminous carpets, or wearing crusts, which have lately come so prominently into favour, the chief object of the makers of these carpets seems to be to try how nearly they can approach the natural rock asphalt in composition, which consists of pure carbonate of lime impregnated with mineral bitumen in variable proportions, that which is best for road purposes being the rock which contains not less than 7 per cent. or more than 12 per cent. of bitumen. In the former case it would be too brittle, in the latter it would be too soft.

In Continental cities, and even in London, very large areas of street surfaces were at one time laid with compressed asphalt. In the year 1872, the author assisted an engineer in laying many thousands of square yards of compressed asphalt on the streets of Budapest, in Hungary, and a most excellent pavement it made.

But during recent years wood pavement seems to have supplanted asphalt in this country, and the introduction of bituminous carpets in place of natural rock asphalt has also affected its use. During the war, also, it must have been difficult, if not altogether impossible, to import this material, and consequently it does not appear to be used so much as formerly.

There are two methods of using rock asphalt for street paving, one known as "mastic," the other as "compressed". It is the latter which is used in streets where there is any considerable traffic; the former is more generally used for footpaths, consequently the author will only deal with compressed asphalt.

Laying Natural Rock Asphalt.—It is evident that if a sound and solid foundation of first-rate concrete is necessary for carriage ways paved with granite setts or wood blocks, it is still more essential that a thin veneer or carpet of asphalt only about 2 ins. thick will require even more support, and consequently this description of pavement must have the same sort of concrete foundation already described. The method of laying the asphalt upon the surface of the concrete should be executed in the following manner:—

The natural rock from an approved mine is first crushed into pieces about the size of walnuts; it is then pulverised in a disintegrator until it is reduced to a fine powder which will pass through a sieve with a mesh equal to 0·10 of an in. This powder is then heated up to between 250° and 270° F. in cylinders, which are kept revolving, so that each particle may become heated without calcining, and still remain separate from its neighbour. The powder is then transported to the street where it is to be laid, in iron-covered carts, in order that it may not lose more than 20° of heat during transit, and thus ensure that it will adhere under compression.

The powder is then spread upon the concrete in an even layer, about 3 ins. in depth, and carefully raked so as to have regularity of depth and surface. Great care must be exercised to ensure that the face of the concrete shall be perfectly dry before the asphalt powder is laid on it, otherwise the moisture is sucked up into the powder, turned into steam, which tries to escape through the powder, and small fissures are formed which may not appear until some time after the roadway has been finished. Such a result leads to the disintegration of the mass with the result that it speedily breaks up under the traffic. After the powder has been laid and raked to its proper thickness of about 40 per cent. more than its finished thickness, it must be well rammed with iron punners weighing about 10 lbs. heated so as to prevent any adhesion of the powder. This ramming must be done lightly at first so as to ensure equality in thickness, afterwards augmented to heavy blows to thoroughly compact and consolidate the particles. After being thus rammed and compressed the surface must be carefully smoothed by a special curved hot iron tool, after which it is again vigorously rammed and well rolled until it is quite cool. The roller weighs about 1,100 lbs. and the finished asphalt is left compressed to a thickness of about 2 ins. A light sprinkling of sand is then spread on the surface and the road is ready to receive the traffic.

It will be seen from the above short description that much skill and care is required to construct a satisfactory compressed asphalt carriage way, and this work is generally prepared by French or Italian workmen, who seem to take an intelligent interest in their work.

Advantages of Asphalt.—Streets paved with compressed asphalt have many excellent features; they have no joints and are quite impervious; they are perfectly smooth and are thus easily cleaned [especially if washed by hose under pressure]; they keep an even temperature, and pedestrians can use them as readily as the footpaths; they are practically noiseless except for the noise of horses hoofs; they are expeditiously laid, and when repairs become necessary they can easily be made; the rapid laying of this method of construction causes less inconvenience to traffic than any other form of pavement, as the traffic can be turned on at once.[1]

The principal objection to asphalt is that it becomes extremely slippery when damp, irrespective of temperature, and this in our climate is frequently the case.

The strewing of sand or "grit" on the surface renders it less slippery, but the best method is that of keeping the surface absolutely clean by frequent washing down with water under pressure from a hose. Another objection to asphalt is that it cannot be laid on streets with a steeper gradient than about 1 in 40 owing to its smooth surface. It has been stated, and experience shows it, that one of the principal reasons for the durability of an asphalt pavement, is that it does not begin to wear until all its compressibility has been exhausted, and that this is the case with no other system of pavement, as wood and stone begin to wear from the day the traffic commences. It has been estimated that under "ordinary heavy traffic" it will take two years to complete the compression, and that the weight of a sample of such pavement removed from the street is practically the same as when it was laid, though the thickness is reduced, thus clearly showing the further compressive action on asphalt by the traffic.

[1] The author heard of a case in London the other day where the actual cost of repairing a sett-paved street was £1 15s., and the watching and lighting cost no less than £4 5s.!

Taking into account all the advantages which asphalt possesses, it is somewhat curious to find that, whereas it is still fairly popular in Continental cities, it does not receive the same favourable consideration in this country.

The next subject to be dealt with is that of—

Durax.—This system of street paving originated on the Continent about thirty-five years ago, where it was introduced under the name of Kleinpflaster [small paving].

It consists of granite, or other hard stone, cut by machine into small random cubes, from 3 ins. to 5 ins. in depth, according to the requirements of the traffic.

These cubes were originally intended to be laid on the existing surface of an old water-bound macadam road as a cheap method of strengthening the surface, and the process was to bed them on a cushion of sand and to grout the joints with dry sand. Those of us who attended the International Road Congress in Paris, in 1903, will remember seeing a sample of this description of paving, at the exhibition in connection with the Congress, and the unfavourable remarks which were passed upon the instability of such a form of construction.

Early trials of Durax confirmed this opinion, and consequently the methods of laying the cubes was materially altered.

The Sidcup Trials.—In the well-known "Sidcup Trials," conducted under the supervision of the Road Board, in 1911, a length of this description of paving was laid in the following manner:—

The surface of the existing macadamised road was scarified and removed and the ground thoroughly consolidated by wetting and rolling. On the ground thus consolidated was laid a layer of tarred limestone chippings to a depth of $\frac{3}{4}$ of an in., and the cubes, $3\frac{1}{4}$ ins. in depth of Leicestershire granite, were laid on this in intersecting segmental circles [known as "oyster pattern"], and were then thoroughly bedded into place by hand ramming.

A grouting mixture, composed of coal-tar pitch tempered with creosote oil or tar, into which was stirred 30 per cent. of fine dried sand, was poured on the surface in a boiling condition and forced into the joints by rubber squeegees. The whole surface was then covered with hot chippings before the grouting had solidified. The total area of this trial section was 802 square yards, and the traffic statistics show that this pavement has been subjected to a daily weight of about 3,500 tons since it was laid. A report on its condition made in 1915, four years after it was laid, says that the surface is clean but somewhat bumpy, and that the cubes showed "considerable signs of wear," and some are fractured in places.

Laid in Birmingham.—Durax was experimentally laid in Hill Street, Birmingham, in 1907, on a gradient of 1 in 18 and 1 in 36. The macadam of the existing road was hacked up and removed, and a cushion bed of sand ½ in. in thickness was spread, and the cubes were laid on this 3 ins. in depth. They were grouted with sand half-way up and finished with a pitch grouting. A portion of this area was paved with Durax on the bridge carrying Hill Street over the London and North-Western Railway and has thus been subjected to considerable vibration. Notwithstanding this, and the fact that it has been opened on more than one occasion for the relaying of mains, it is still there and in fair condition.

Durax has also been laid in Birmingham in King Alfred's Place and Swallow Street, where 2¾-in. cubes were laid in segmental courses [or oyster pattern] on a bed of bituminous binder 1⅛ ins. thick, the cubes well rammed into it, and grouted with a mixture of pitch and creosote oil. This was laid on an existing macadam road, the surface of which was trimmed down, and strengthened where necessary. Since then no more Durax has been laid on this description of foundation, but in 1912 and 1915 certain lengths were laid on a foundation of 6 to 1 Portland cement concrete 7½ ins. deep; the cubes were 2¼-in., laid "oyster pattern," bedded on ½ in. of sand and grouted with a cement grout composed of 2½ sand to 1 of Portland cement. This pavement is still in fair condition.

Laid in Guildford.—Durax was laid also on the Brighton

Road, Guildford, in 1906-7, in a similar manner to that at Birmingham, except that the cubes were grouted with sand as before, but were finished with a Portland cement grouting. It replaced old worn-out granite setts on a 6-in. granite foundation; a further 6 ins. of concrete was added and the Durax was laid on this.

This made a very rigid job. There was no cushion bed provided, and consequently the edges or arrises became chipped and broken, but otherwise this paving is still in good condition, though subjected to a heavy but slow-moving traffic.

It was also laid in Nottingham, in 1906, but from a report in my possession it is stated, "the setts visibly move as a wheel passes over them, but they appear to maintain their general level and not to become more than very slightly loose".

Durax has been laid on the streets and roads of a considerable number of cities and towns in this country, with varying results, and seems to have had a chequered career.

Laid on the Thames Embankment.—The best example of which the author is acquainted, is that laid in 1912 on the Thames Embankment, westward of Chelsea Bridge, where a long length of this form of construction can be seen. The existing macadam was hacked off and removed and the cubes laid on the existing road formation which had been well consolidated by the traffic. The cubes were bedded on tarred chippings and grouted with hot pitch. The surface seems to have stood up against the traffic very well, though the author understands that the whole surface was re-grouted in 1917, which may have considerably helped it. The traffic, however, is not great on this road, and as it is of considerable width, the traffic is not concentrated.

On the whole, therefore, Durax may be a good substitute for ordinary water-bound macadam in certain localities, but it cannot claim to have the advantages which rest with wood blocks, granite sett paving, asphalt, or even some of the better forms of bituminous roads, or bituminous "carpets," or other forms of surface protection. Indeed it does not appear to have any advantages over a well-made granite paved street, where it has to be paved on a concrete foundation, except that of being somewhat cheaper in first construction.

Finally, a few words on bricks as a pavement will conclude this chapter :—

(5) **Bricks.**—Bricks, made of clay, as a material for paving streets have not found much favour in this country, although at one time they were somewhat extensively used for paving footpaths. In America, however, and some other countries, notably Holland, they have been, and still are used for paving carriage ways to a considerable extent.[1]

This is probably due to the fact that suitable stones or other materials are not to be found in the neighbourhood, although there may be an abundance of clay from which bricks can be made, and they are consequently used. This is confirmed when we read that, " Brick is the chief paving material employed in most of the smaller cities of the Mississippi Valley ".

They are also largely used in Canada, for in a paper read before the Association of Ontario Land Surveyors, by a Mr. Tyrrill, he stated that for ordinary traffic, " of say 500 vehicles per yard of width per day and less, a good quality of vitrified brick pavement should give excellent results and be preferable to asphalt ".

Mr. Tyrrill evidently had a very high opinion of bricks as a pavement to make such a statement as that, with which the author cannot agree. In the year 1881, some highly vitrified " Tees Scoriæ " bricks were laid in Liverpool as a trial, but they were not successful. They wore very unevenly, and were found on examination by breaking that many of them had large holes where they had not properly fused together ; they also wore exceedingly slippery, as when the " scale " had been worn off it left a surface like glass, and the street became dangerously slippery. They were consequently removed and granite setts substituted.

[1] From a return published in the " Municipal Journal " of New York, dated 5th March, 1914, it appears that no less than 6⅓ million square yards of brick paving had been laid in 700 United States cities !

The author is not aware of any town in Great Britain where ordinary bricks are used as a street paving material.

In the well-known American book on roads, "Text-book on Highway Engineering," by Arthur H. Blanchard and Henry B. Drowne, the authors give a summary of the advantages of bricks as a street pavement.

But notwithstanding these encomiums it is doubtful if bricks would be used if other more suitable materials were available, and it is unlikely that bricks will ever find favour in this country as a street paving material.

Bricks or Blocks made with Cement.—Attempts have been made from time to time, however, to construct paving bricks or blocks of various materials, including, of course, ordinary cement concrete blocks made with a fine aggregate. The author constructed paving blocks many years ago in the following manner:—

An open wooden frame about 3 ins. in depth, lined with thin sheet-iron fixed to the sides and ends with counter-sunk screws, was laid on a flat table. Boys were engaged to pack the bottom of the frame [which afterwards became the surface] with ordinary $2\frac{1}{2}$-in. and 2-in. dry, broken macadam, taking care to lay the flat end downwards. The interstices were then filled with small chippings and a fine cement mortar was then carefully rammed with small wooden punners into the frame until it was full. The result was a concrete block with its face composed of granite macadam set as a "mosaic". These blocks were made of various sizes for convenient "handling," so as to break joint when laid, and when well matured were principally used for macadamised road crossings, entrances to private yards or carriage drives, and for other purposes. No street that he can remember was ever entirely paved with these blocks.

Clinker Bricks.—Attempts have also been made to construct paving blocks out of crushed refuse destructor clinker, by grinding the clinker very small, which was then dried and heated, and mixed with hot liquid Limmer asphalt; then whilst hot each brick was subjected to considerable pressure in a hydraulic press. The absorption of moisture by these bricks was rather remarkably small when the composition of the aggregate is considered, as it was only $\frac{1}{32}$ of a lb. per brick.

A few streets of light traffic were laid with these blocks, but in process of time they began to disintegrate and crumble and the experiment was abandoned.

Wood's Clinker Blocks.—A much better paving block has been made by Mr. Francis Wood, M.Inst.C.E., the Borough Engineer of Fulham, with clinker from his refuse destructor by using Portland cement or lime as a matrix instead of bitumen, and by carefully grading the clinker which was first crushed to about $\frac{3}{4}$ in. or less, and then graded as follows:—

Passing 200-mesh.	5 per cent.
,, 100 ,,	6 ,, ,,
,, 80 ,,	8 ,, ,,
,, 50 ,,	10 ,, ,,
,, 30 ,,	20 ,, ,,
,, 20 ,,	12 ,, ,,
,, 10 ,,	20 ,, ,,
Left on 10 ,,	19 ,, ,,
Total	100

About 2 tons of clinker are required for the manufacture of 1,000 blocks which are of the following size: $8\frac{3}{4}$ ins. by $4\frac{5}{16}$ ins. by $2\frac{9}{16}$ ins.

The graded clinker is mixed with the cement or lime in the proportions of 4·48 lbs. of clinker to ·40 lb. of lime or cement, and a very small quantity of water. The material is placed in a moist condition in a mould under a press and subjected to a pressure of 400 tons to the square foot, carefully taken out and left for about 3 days to partly set, then stacked, and in about 13 weeks the blocks are ready to be used.

Finally under "Bricks" may be mentioned—

Lithofalt Blocks, which was a trade name given to a paving block manufactured by the Limmer Asphalt Paving Company, the composition of which appears to be some form of asphalt and very small aggregate. The advantage of these blocks consisted in their small depth, only $1\frac{1}{2}$ ins., and it is interesting to note that Mr. Oliver E. Winter, the Borough Engineer of

Hampstead, was able to take advantage of this. He stated[1] that some of the wood-paved streets in his district were on concrete foundations of insufficient strength to sustain the traffic, and that "to have repaved the streets with wood blocks, it would have been essential to entirely reconstruct and deepen the concrete foundation which would have entailed a very heavy expenditure". He considered that if he could obtain a thinner material for surfacing he might add 3 ins. to the concrete foundation and thus strengthen it. "After a very careful investigation into all materials that were available under such limited conditions," he selected the "Lithofalt block," and the following is a description of this method of street paving:—

"The Lithofalt blocks, 9 ins. by 4½ ins. by 1½ ins. in depth, were obtained from the makers, the Limmer Asphalt Paving Company. Three inches of new Portland cement concrete was laid over the existing foundation, including 1 in. of cement rendering, in which the blocks were bedded by tapping with a wooden mallet before setting takes place. My paviors carried out the laying of the blocks in an expeditious manner without any preliminary experience, the four paviors engaged laying 300 sup. yds. per day. The surface of the blocks was finally brushed over with cement grout to ensure the proper filling of the joints.

"The result of a two years' test of this paving was so satisfactory to my Council that the paving was recently extended by about 6,000 sup. yds., and it has been decided to pave two other streets during the current year.

"One of these streets is at present paved with macadam, and as the foundation is a substantial one, it is proposed to remove the top coating of metalling to a depth of about 3 ins., and then to place over the old road a concrete bedding, 2 ins. in depth, upon which the Lithofalt blocks will be laid. An excellent paved road will thus be obtained, at a cost much below any similar kind of impervious paving.

"The blocks are also made 1¾ ins. and 2 ins. in depth to suit the various grades of traffic.

[1] *Vide* "Paving of Town Streets Sustaining Medium Traffic," a paper contributed by Mr. Winter to "Practical Road Engineering," published by the St. Bride's Press, Ltd., Bride Lane, E.C.

"The paving generally has given very great satisfaction; it is easily kept clean; from a sanitary point of view it is unsurpassable, and has all the advantages of ordinary rock asphalt, but, at the same time, affording a better foothold for horses in all conditions of weather. It is readily laid, and trenches repaired by the usual staff kept by a road authority. Judging from the paving which has now been down over two years, under considerable traffic, it promises to be a paving of a good, durable character, and it may be safely estimated to have a 'life' of ten to twelve years, and for streets with less traffic probably considerably more."

The author understands that this form of paving block has stood the traffic very well, and is still in a satisfactory condition, after being down for ten years.

This description of paving has also been laid in various cities and towns in this country, and also in America, and some of our "Overseas" Dominions.

An American Block.—The following is a description of an asphalt block as made in America, constructed of trap rock, powdered limestone, and bitumen, but it does not give the proportions of these ingredients, except that the bitumen content of the blocks should be between 6·5 and 8·5 per cent., depending on the grading of the mineral aggregate, and the method of manufacture. Details, however, are given of the "mineral aggregate" [presumably limestone] as follows:—

	Per Cent.
Passing 200-mesh sieve	20 to 35
,, 80 ,, ,, and retained on 200-mesh sieve .	7 ,, 15
,, 20 ,, ,, ,, ,, ,, 80 ,, ,, .	12 ,, 30
,, ¼-inch screen ,, ,, ,, 20 ,, ,, .	30 ,, 50
Retained on ¼-inch screen	nil.

The absorption of water by the block after immersion for seven days should not exceed 1 per cent.

These blocks are made of the following dimensions: 5 ins. in width, 12 ins. in length, and 2, 2½, or 3 ins. thick, depending on traffic conditions [1]

The author will now pass on to consider the question of Concrete Roads.

[1] *Vide* "Transactions of the American Society of Civil Engineers," vol. lxxxii., December, 1918.

CHAPTER IX.

CONCRETE ROADS.

HITHERTO the attempts that have been made in this country to construct unsurfaced concrete roads have not met with much success, although in the United States of America, in Canada, and elsewhere many millions of square miles of roads of this form of construction have been laid. It is estimated that at the present time upwards of 50 million square yards of such roads exist in America alone, and that, with few exceptions, they are a success.

In this country only a few thousand yards have been laid, and, in some cases, these roads have not been altogether satisfactory, except in a case which is dealt with at the end of this chapter.

Objections to Concrete Roads.—The objections that have been raised to this description of construction may be enumerated as follows:—

(1) All traffic must be diverted during construction, and for at least three weeks afterwards in order to allow the concrete to set properly, and this dislocation of traffic is naturally objectionable.

(2) It is contended that the hard, non-resilient nature of this form of construction causes a noisy rattling of vehicles with iron or steel tyres, and that horses' hoofs are jarred if constantly travelling on such a surface.

(3) That concrete is liable to crack when laid in "monolith," and that even when laid in "bays" with expansion joints it does not altogether prevent the ultimate appearance of these cracks.

(4) That it is not an easy road to break up for the purpose of digging trenches for gas, water pipes, etc., and that

the reinstatement of these trenches is somewhat difficult and takes a long time to set.

(5) That the unprotected surface of concrete will not stand the hammering and grinding action of the traffic so long as iron or steel tyres are in use, and so long as iron-shod horses use our roads.

(6) That it is liable to become dusty in dry weather.

(7) That the concrete must be very rich in cement in order to secure success, and that this makes it an expensive road to construct in comparison with other forms of construction.

(8) That such a road would require most careful and constant supervision during construction.

Answers to Objections.—Taking these objections into consideration *seriatim*, with suggested answers, they are as follows:—

(1) It is perfectly true that concrete should be given a sufficient period of complete rest to thoroughly consolidate, but this objection pertains in the same manner to concrete foundations for all descriptions of paved streets or roads, perhaps in a minor degree, but in this connection most of the failures and uneven wear of such paved streets is due to the mistake of allowing the traffic on to the work too soon. There are many cases where, even if the traffic cannot be altogether diverted, it is possible to execute one-half of the road longitudinally, allowing the work to consolidate before diverting the traffic on to the finished work.

(2) This contention as to noise is exaggerated. If the finished surface of the concrete is made perfectly smooth and level there should be little or no noise, and it is evident that, as the use of iron or steel tyres becomes obsolete, and the tendency of the age is in this direction, such an objection becomes negligible. In any case, any possible noise must be less than that on a road paved with hard stone setts, and as to the ill-effect on horses' hoofs, or their fetlocks, this is possibly overstated.

(3) There can be no doubt that the tendency for concrete to crack is one of the chief, if not the principal, objection to

this form of road construction; but if the concrete is properly prepared and laid in accordance with a rigid specification, this objection can be overcome. A further reference to this will be given in due course.

(4) It is also true that a well-made concrete road is not so easy to break up as are roads of a less rigid form of construction, and that reinstatements would require special skill and care. This matter will also be referred to later in this chapter.

(5) This objection is partly met by the observations above in reply to objection 2. To meet this objection, and for other reasons, it has been found advisable in many cases to apply a coating of tar or pitch to the surface of concrete roads, which, of course, entirely eliminates this objection.

(6) This objection is easily met by tarring the surface.

(7) This matter will be dealt with later in this chapter.

(8) This is perfectly true, considerable care must be exercised in construction. American road engineers state that 90 per cent. of concrete failures are due to poor workmanship, 8 per cent. to poor aggregates, and only 2 per cent. to poor cement.

In June, 1917, as Chairman of the Council of the Roads Improvement Association, I wrote a pamphlet which was duly printed and issued, entitled "Concrete Roads: the present position and possible future of concrete roads in this country," and I cannot do better than refer somewhat copiously to this pamphlet, as it contained most of the available and up-to-date information on this subject.

It is necessary to emphasise what I then stated so that there should be no misapprehension as to my attitude with regard to the question, viz. :—

Concrete Roads Merely a Substitute.—"It is not suggested that the use of concrete, as a road material, should take the place of other materials, but that this description of road construction might be included in the practice of road building, and should be given a better chance in the future, than it has received in the past, to prove, or disprove, its merits."

American Engineers' Opinions.—Nearly all the most eminent highway engineers of America have expressed favourable opinions with regard to this form of road construction.

Mr. Stern, the Chief Engineer of Highways of Manhattan, stated that "it answered all the essentials of a thoroughly first-class pavement at the lowest cost. Its adaptability both for horse and motor vehicles in all kinds of weather, for twelve months in the year, its smooth surface and comparative noiselessness, coupled with its extremely low total annual cost, compared with any other type of pavement, would appear to guarantee for it a very wide use throughout this country".[1]

Mr. Stern also gave to the Congress a paper in which he described nine different types of road construction, which showed that in comparison with other well-known forms of road construction, concrete roads were considerably cheaper in the long run than any other form of construction.

In 1914 a very representative meeting of engineers was held in Chicago, at which a large number of papers were read on the subject of concrete roads, and the general opinions there expressed were unanimously in favour of such a method of construction. The movement in favour of concrete roads in America is supported by the Government, the State Boards, the Municipal Boards, by many of the Universities, and, as has already been stated, by most of the leading engineers of the country.

In face of this consensus of opinion, it is idle to dismiss the possibilities of concrete roads, or to contend that the movement in this direction is merely due to the anxiety of Portland cement manufacturers to sell their goods.

Climatic Conditions Negligible.—Nor can the contention hold good that the climatic conditions of the United States make it possible successfully to construct concrete roads, whereas in our country the climate is against such a form of construction, when we find that in Sioux City, Iowa, U.S.A., there are upwards of a million square yards of concrete roads, some of which have been down more than six years, and where

[1] *Vide* "Proceedings of the Second National Conference on Concrete Road Building," held at Chicago, February, 1916.

they were laid under very trying climatic conditions, the temperature ranging between 35° F. *below* zero up to 115° F., and where there are frequently terrific rainstorms. The roads are universally 6 ins. in thickness, not reinforced, the concrete consisting of 1 of cement, 3 of sand, and 5 of broken stones. The traffic is stated to be "very heavy" in some of these streets, and it is on record that there are no cracks or settlements in any one of the carriage ways constructed of concrete. This excellent result is attributed to "very careful workmanship," careful selection of the materials, and proper mixing. It is claimed that these roads are not slippery, though some of them are laid on gradients as steep as 1 in 9.

Care Gives Good Results.—It appears from a careful study of the American practice that these good results have not been obtained without a very careful study of the question; numerous tests and trials have been made of materials, and also as to the behaviour of concrete under varying conditions, whilst many conferences have been held by engineers to discuss questions of the right methods to be adopted. These questions appear, *inter alia*, to be the right proportions of the materials, the consistency of the wet concrete, the size and description of the aggregate, the strength of the aggregate, the proportions of the different sizes of the aggregate, the proportion of water to be used, the reasons for surface cracking, the amount and effect of expansion and contraction, the amount of friction between the slab and the sub-base, the best methods for mixing the concrete and placing it *in situ*, the finish of the surface, the organisation of the labour employed, and many other details.

Some of these details, which follow, are given as examples of the American practice, and are worthy of careful study by any road engineer who is contemplating the construction of a concrete road.[1]

Essentials of Good Sub-grade.—Cracking of a concrete pavement is due generally to the unequal settlement of a poor

[1] Specification for concrete roads from a paper by H. Ettinge Breed, First Deputy Commissioner, New York Commission of Highways, read at the Annual Convention of the American Road Builders' Association.

sub-grade. If the road is to be satisfactory it is of first importance that a good sub-grade be secured. These we consider the essentials of a good sub-grade :—

(1) It must have uniform bearing power.

If an old road-bed is to be used it must be scarified, reshaped, and re-rolled for the entire width of the pavement, removing all large stone to a depth of 6 ins.

(2) It must be dry.

Ditches should be low enough to take away the water from under the pavement. With unstable soil good results can be secured by providing sub-drains and spreading a layer of gravel—preferably run-of-bank gravel—over the sub-grade to increase its stability. Material used for this purpose must be impervious ; if it is porous it will act during wet periods as a reservoir, which, under conditions of frost, will break the pavement proper.

(3) It should have metal reinforcement (*a*) under very bad, i.e. unequal soil conditions ; (*b*) whenever the supporting power of the sub-grade changes, as from rock to earth, or passing over a trench.

Our experience indicates that the expense of reinforcement is not justified in gravelly or sandy soils where good natural drainage prevails.

The Mix.—The mix should be proportioned in such a manner as to give the greatest density. With our requirements for materials we have found that the proportions of 1, 1½, 3, most nearly do this. Our specifications provide that the concrete shall be mixed in the proportions of 1 volume of cement to 4½ volumes of sand and broken stone or gravel, and the proportions of fine and coarse aggregate are varied slightly as a result of field void tests, so that the greatest density is obtained. Should the size or character of the materials change there would be a corresponding change in the proportioning of the mixture.

The coarse aggregate should consist of a well-mixed product of clean No. 1, No. 2, and No. 3 stone or gravel.

No. 1 size is that retained on a ⅜-in. circular screen and passing a ⅝-in. circular screen.

No. 2 size is that retained on a $\frac{5}{8}$-in. circular screen and passing a $1\frac{1}{2}$-in. circular screen.

No. 3 size is that retained on a $1\frac{1}{2}$-in. circular screen and passing a $2\frac{3}{4}$-in. circular screen.

It is provided, however, that not more than 25 per cent. of the total shall be No. 1 size, the proportions being so graded as to give a minimum of voids.

Aggregates should never be used unless they comply with the tests prescribed.

You may note that we allow, as our maximum size, stone that will pass a $2\frac{3}{4}$-in. ring, whereas most specifications permit only $1\frac{1}{2}$-in. stone as a maximum. This may seem radical, but our reason for the increase in size is that we get equally as good, if not better, results from the larger stone, and at a cost decidedly lessened by our using more nearly the product of the crusher. Especially is the price to be considered on contracts where the local supply is crushed on the ground, as is the case in most of our work. If you desire economy, this change is worthy of your consideration. We save 15 per cent. in crushing costs by this use of stone larger than the previously accepted standards.

From a practical standpoint, a pile of stone graded from $\frac{3}{4}$-in. to $2\frac{3}{4}$-in. has more stability when properly mixed than stone graded from $\frac{3}{4}$-in. to $1\frac{1}{2}$-in. In our 1916 work we used stone up to $2\frac{3}{4}$-in. in size. As an indication of the compressive strength per square inch of field cubes, tested at an age of twenty-eight days, we have a grand average of 3,370 lbs. per square inch for 504 cubes of stone and gravel, of which only $13\frac{1}{4}$ per cent. were under 3,000 lbs. Greater density can be obtained by using stone up to $2\frac{3}{4}$-in. in size, and with the larger size stone there is less probability of spalling at joints and along edges.

Sand.—Concrete pavement sand should be such that 100 per cent. should pass the $\frac{1}{4}$-in. screen; not more than 20 per cent. should pass a No. 50 sieve, and not more than 6 per cent. should pass a No. 100 sieve. However, where more than 20 per cent. of the sand passes a No. 50 sieve, where it is well graded to give a low percentage of voids, and where it conforms to all other requisites, special permission for its use may be given by the chief engineer. Sand may be rejected if it contain more than 5 per cent. of loam or silt.

Method of Mixing.—The concrete should be mixed in approved mechanical batch mixers. Mixing should be continued at a speed of not less than 10 revolutions nor more than 16 revolutions per minute, for at least one minute after all materials are in the drum and before any discharge is made.

If at any time during the progress of the work the temperature is so low that in the opinion of the engineer in charge of the work it will within twenty-four hours drop to 35° F., the water and aggregates should be heated and precautions taken to protect the work from freezing for at least ten days. Should these temperature conditions persist for two consecutive days, permission should be obtained from the chief engineer before proceeding. He will lay down such requirements of procedure as may be permitted. Such procedure should be only for emergency work. In no case should concrete be deposited on a frozen sub-grade.

Further American Views.—At the International Road Congress held in London in 1913, Mr. A. N. Johnson, the State Engineer to the Illinois Highway Commission, gave a paper on "Concrete Road Construction," in which he stated, *inter alia :* "The possibilities of this form of construction, together with the very promising results obtained in the past few years, make it worth the study and investigation of highway engineers". He pointed out that concrete required provisions to meet the expansions and contractions due to changes of temperature. That it possessed very little resiliency to resist blows and shocks, that it was brittle and liable to depressions in the surface, and that to meet these difficulties, great care was necessary in its construction, and that expansion joints must be provided. He says also : "If a successful concrete pavement is to be laid, a concrete rich in cement must be used," and he recommends 1 of cement, 2 of sand, and

$3\frac{1}{2}$ of broken stone aggregate. Mr. Johnson points out other important precautions that are necessary, but does not deal in any way with reinforced concrete roads. His paper concludes with the following remarks, which are given in full, as they appear to very fairly sum up the advantages and disadvantages of such a carriage way:—

"In adopting concrete for a road surface, it should be borne in mind that if a hard rigid form of pavement is undesirable for the traffic to be accommodated, it will not prove satisfactory. For example, with a large amount of light, horse-drawn traffic some more resilient form of pavement would be found better adapted; but where a large amount of motor and heavy horse-drawn traffic is to be provided for, concrete pavements are proving satisfactory. There are experimental data at hand which seem to indicate a concrete pavement to be one of the most durable forms of construction that have been employed, and, under many conditions, the most economical.

"The wide distribution of materials suitable for concrete makes this form of construction of the widest application, and, in fact, in many areas where there is nothing but gravel deposits, poor for ordinary road purposes, a concrete road becomes the most economical and durable pavement possible. Moreover, it does not require exceptional skill on the part of the workmen, but may be successfully laid, under careful supervision, with any reasonably good labour."

In February, 1914, a "National Conference on Concrete Road Building" was held in Chicago, which was attended by most of the leading highway engineers of the United States of America. The various papers contributed to this conference form very interesting reading, but it would be impossible to produce more than a few extracts from some of these papers which bear directly on the question of how to construct concrete roads which will stand a mixed traffic. The following is a description of how this work is carried out in Wayne County, Michigan:—

Description of an American Concrete Road.—"As soon as our drainage is cared for and our road-bed is prepared we haul our material to the job and pile it conveniently alongside of the road. We endeavour to pile our material in such a manner that as our mixer backs up our supply of material will remain in easy reach.

"Our roads are constructed from washed and screened gravel ranging in size from $\frac{1}{4}$ to $1\frac{1}{2}$ ins. and washed and screened sand. We are very particular to have our aggregates free from clay, loam, and other foreign substances. We use gravel in the construction of our roads because we have no other local stone available that is satisfactory. The limestone in Wayne County is very soft, so we purchase gravel of the proper quality because we can buy it at a cheaper price than we can buy any other material.

"When our materials are in place along the roadside we set our side forms. At intervals of 25 ft. we set in place the steel plates which we use to protect the pavement at the expansion joints. These plates are of soft steel about 3 ins. in width and $\frac{3}{16}$ of an inch in thickness with sheer members which extend out 6 ins. on each side into the concrete.

"We utilise a rich mix of concrete because we believe it pays to use plenty of cement; the function of the cement is to act as the binder. The mix we use is nominally $1 : 1\frac{1}{2} : 3$. In reality, the mix is $1 : 3$ with sufficient sand to fill the voids —about 7 per cent. or 8 per cent. plus. We use a wet mixture, and in mixing we specify that the concrete shall be turned about 50 or 55 seconds. We have made some few tests on turning the mixer, 4, 8, 12, 16, 20, 24, 28, and 32 revolutions, and we find that the average from the revolutions at 16 over those at 12 to 28 shows an increase in strength of about 25 per cent.

"Before we place the concrete we wet down the sub-grade thoroughly to prevent its taking moisture out of the concrete. In placing concrete we utilise the side rails. These side rails are steel shod, and the templet we use, which is cut to form the crown of the road, is also steel shod.

"After the concrete is in place we do not permit anyone to step on it or to throw anything on it, or interfere with it in any way. The final finish is made with wood floats, which keep the road from being slippery. The edge of the road is pared down about 3 ins. so that there will not be too sharp a division line between the edge of the finished concrete and the earth, gravel, or macadam alongside.

" To prevent the concrete from drying out too rapidly we cover it with any material which is handy at the roadside and sprinkle it continuously for at least eight days. We keep the traffic off for at least two weeks in warm weather, and as long as six weeks in cold weather.

" Our concrete roads offer the best of service 365 days in the year for all types of vehicles. They are not slippery in wet weather, nor are they dusty in dry weather. The traffic to which some of them are subjected approximates 2,500 vehicles a day. We have spent less than $100 a mile to maintain the first roads we built for the five years that they have been down, and in view of the service of the roads and their low cost of up-keep we consider our concrete pavements a good investment."

One of the roads in Wayne County, constructed in this manner, is 28 miles in length, and is said to be dustless, and wearing well.

Another American View.—With regard to the concrete roads of the Ohio State, Mr. Bruning, a " Division Engineer," gave a paper descriptive of various failures due to cracks and contraction and expansion of the concrete, and finished with the following conclusions :—

"(1) That careful and intelligent inspection and the use of only first-class material are essential to the construction of concrete pavements to insure permanency.

"(2) That the use of bank run gravel or crusher run limestone should not be permitted.

"(3) That a rich mixture is necessary as a factor of safety against irregularities in the mixing and placing of concrete.

"(4) That the wearing quality of the pavement is often greatly impaired by insufficient protection against too rapid drying.

"(5) That there is no apparent difference in the permanency of pavements constructed on either a flat sub-grade or on a sub-grade having a crown.

"(6) That the weakest points in the pavement are at the expansion-contraction joints and that tarred felt is preferable to a poured joint.

"(7) That the part of the shoulders next to the concrete pavement should be reinforced by placing stone or gravel macadam on 1 to 2 ft. of the shoulders next to the pavement. This will avoid the usual formation of a rut in the shoulder, which tends to retain the surface water.

"(8) That a bituminous surface treatment is not essential to a good concrete pavement.

"(9) That observations indicate there is no special value in roughening the surface of the concrete preparatory to putting on the surface treatment, and such roughening will tend to increase the wear if the surface coat is worn away and not replaced.

"(10) That asphalts used as a surface treatment for concrete have peeled more than tars.

"(11) That the results secured in the surface treatment of the present time do not warrant its use in great quantities, but experiments should be carried forward in sufficient number to learn further facts and establish, or disprove, those already thought to be known.

"(12) That first-class concrete pavements have every indication of ability to stand up under heavy steel-tyre traffic."

Contraction and Expansion.—There is a lengthy and elaborate report by a Committee on the "Contraction and Expansion of Concrete Roads," which they attribute to—

(1) Changes in the temperature of the concrete.

(2) Variations in the moisture contained in the concrete.

(3) Variations in the condition and character of the sub-base.

(4) Excess loading by the traffic.

Elaborate explanations of the above causes of failure follow, with the result of careful investigations as to the amount of expansion and contraction caused by the above factors. They state, *inter alia*, "it has been definitely established that with an increase in moisture content there is an expansion of the concrete, and with a decrease of moisture, a contraction". They also state that there is more or less movement by expansion or contraction of the concrete depending on the character of the sub-base. Longitudinal cracks are generally due to an unstable sub-base, although sometimes occurring through temperature; transverse cracks are mostly due to excessive moisture in the concrete and temperature conditions.

A bay, or slab, of concrete should not exceed 30 ft. in length to avoid cracks, but this depends on the constitution of the concrete and the character of the sub-base. It also depends on the thickness at which the concrete is laid.

Reinforcement.—With regard to reinforcing the concrete the following decisions were arrived at, viz. that reinforcement would be of value—

(1) When the foundations are uncertain.

(2) Where there is little rainfall and long or wide slabs are desired.

(3) Where there is insufficient water for "curing".

(4) Where it is necessary to have a thin slab.

(5) When a decided change in gradient occurs.

(6) Where any difficulty occurs in jointing.

(7) Where the width of the slab is more than 25 ft.

One would have thought that another reason for the addition of reinforcement would have been where an abnormal heavy weight of traffic was to be met, and also where the haunches of the road could not be made sufficiently strong.

Further Investigations Desirable.—There is a great deal of further useful information contained in this report which concludes with the following suggestions for further investigation:—

(1) The determination of the friction of a concrete slab on different materials and under different conditions of the sub-base.

(2) A more accurate determination of the modulus of elasticity of concrete in tension and compression.

(3) The determination of the variation in the coefficient of expansion of concrete when under stress.

(4) The determination of the expansion of green concrete due to the chemical action of the cement during setting.

(5) A more accurate determination of the coefficient of expansion of different mixtures of concrete.

(6) The determination of the effect of change of moisture content in concrete when under stress.

(7) The determination of the bond between steel reinforcement and concrete when the concrete expands or contracts due to change in moisture content.

(8) The determination of the bond between steel reinforcement and concrete when the concrete expands or contracts due to change in temperature.

(9) The determination of the absorption of heat by concrete uncovered and covered with a bituminous carpet.

(10) The determination of the effect of continual alternate expansion and contraction of unrestrained and restrained concrete.

(11) The determination of the permanent set resulting in wet and dry concrete under various tensile and compressive stresses.

Committees also investigated and reported on the question of aggregates, and also on the foundations, or sub-grades, and other matters which are well worthy of study by anyone who is contemplating the construction of concrete roads. It is evident that the road engineers of America are giving much more scientific attention to the question of concrete roads than pertains in this country, but the reason may be that there are some districts in that mighty continent where other materials suitable for road construction cannot be found and the cost of freight would seriously interfere with the financial question.

It is unnecessary to give any further details of the American practice ; it is evident that considerable attention is given to this method of road construction, and as the Engineer of Victoria, British Columbia, said in connection with this subject, " when concrete roads are being laid for the first time, the more 'cast-iron' you can make the specification the better. If they are started right there is more likelihood of a better finish!" It is proposed, towards the end of this chapter, to give an example of such a "cast-iron" specification suitable for the construction of a concrete road in this country, as hitherto it does not appear that sufficient attention has been given to "starting right," and consequently the "finish" has not been all that could have been desired.

Before giving particulars of what has been done in connection with concrete roads in this country, the following particulars with reference to the attempts that have been made in other European countries may be of interest:—

Belgian Trials.—In Belgium, concrete roads have for some time been made in the following manner: the ground is excavated to the required depth and contour on which is laid a layer of large broken stone. This is watered and rolled to a moderate degree of consolidation. A concrete is then made of 10 volumes of pulverised slag, 2 volumes of slacked lime, and 1 volume of a slow-setting Portland cement. This concrete is then laid about 1½ ins. in thickness on the prepared foundation and a layer of about 2 ins. of ordinary broken macadam laid thereon; it is lightly watered and then rolled. The concrete is partially squeezed into the lower bed of broken stones and partly into the top layer. This is, of course, not strictly a concrete road, but is given as an instance of how concrete may be used in carriage-way construction. Such a road is an improvement on the ordinary water-bound macadam road, but is only suitable for very light traffic. A considerable time is necessary before traffic can be turned on to such a road, as of course it is necessary for the concrete to set properly.

French Trials.—Another modification of this Belgium process is a method employed in France, which is called "Reinforced Macadam". In this case the ground is excavated to the proper width and contour, a layer of Portland cement concrete about 3 ins. in depth is laid thereon, on which is placed a sheet of expanded metal in the form of wire with a large mesh. This is covered with a layer of fine concrete to a depth of about 1½ ins., and on this is placed, by hand, broken stone spalls about 4 ins. in size with their flat surfaces upwards. These are then gently beaten into place and forms a sort of mosaic pavement. Where hand labour is cheap, this form of construction is no doubt better than ordinary macadam, but it can scarcely be called a concrete road as the surface is protected by the stone spalls; it is more akin to chip pavements which are referred to on p. 223.

German Trials.—In Germany, paving blocks about 6 ins. square are made of slag concrete and then used in a similar manner to stone paving. This of course has the advantage of ensuring that the concrete is well matured before being subjected to traffic. Concrete roads, pure and simple, are also laid in some parts of Germany and are known as the "Kieserling" pavement. A fine concrete, consisting of broken basalt and Portland cement, is laid on a concrete foundation before it has quite set, this upper crust being only 2 ins. to 2¾ ins. in thickness; expansion joints are provided, and this form of concrete paving is said to be fairly successful under light traffic.

So far the attempts to construct concrete roads in this country have been very few, and they appear to be as follows:—

Leith Trials.—It has been stated that concrete roads have been constructed in Leith, near Edinburgh, for the past thirty years, but that they have not been altogether successful, probably because they were not constructed under a "cast-iron" specification. About two or three years ago a reinforced concrete road was laid at Chiseldon, near Swindon; it was constructed for military purposes, and was originally intended to have an asphalt surface, but it was left as it was, and has proved satisfactory. A layer of cinders was laid on the sub-base, rolled to a finished thickness of 3 ins., and the concrete 6 ins. in thickness was laid thereon.

Chester Trials.—In the City of Chester, Mr. Matthews Jones, the City Engineer, who is a well-known advocate of concrete roads, has constructed several streets in this manner.

The following is a brief description of the methods he employed:—

"The aggregate is as follows: 1 ton of 2-in., 1½ tons of 1½-in., 1½ tons of 1-in., 1½ tons of ¾-in., and 1 ton of ½-in. broken stone, which were thoroughly mixed together, in order to eliminate the voids as much as possible. Where the sub-base is wet or composed of clay, he places at least 2 ins. of ashes thereon. On this he puts from 2½ ins. to 3 ins. of concrete for a length of anything from 25 to 50 lineal yards, the full width of the carriage way. On this he places his reinforcement, with the stronger bars laid transversely. Then the next layer of concrete, whilst that underneath is still fresh. The surface is then finished with the flat side of the spade; no floating is done. He keeps the surface ¼ in. higher than the finished contour, to allow for shrinkage. Each length of concrete is finished against a board laid across the street, which board is removed as the other length of concrete is put in. This gives an upright finish, and also acts as a transverse expansion joint.

"The traffic is kept off three weeks, and the surface is kept well watered. Finally the surface is tar sprayed and covered with ¼-in. granite chippings."

The result has been extremely satisfactory, though it is fair to state that these roads are not subjected to a very heavy traffic, only about 60 tons a day, which reduced to the usual standard gives about 3,000 tons per yard width per annum.

Dunfermline Trials.—In Dunfermline, Scotland, a concrete road was constructed in the year 1916. It was 15 ft. 6 ins. between the kerbs, and not subject to heavy traffic. It was laid 6 ins. in thickness and reinforced. After the sub-base, or foundation, had been properly prepared, 2 ins. of concrete was laid, and on this was spread the wire reinforcement which was covered with another 2 ins. of concrete, whilst a final 2 ins. finishing coat of concrete was laid on this. The lower layers were not allowed to set before the other layers were laid on them. The two bottom layers consisted of 1 cement, 2 sharp sand, 3 broken whinstone [1½-in. gauge]. The finishing coat consisted of 1 cement, 2 ¼-in. granite chips and dust, 2 whinstone chips [½-in. to 1-in. gauge]. When the surface was about "three parts set" it was gone over lightly with a bass broom [thus securing a "key" for the tar spray], and was kept covered with sand, which was kept moist for seven days, and was removed at the end of fourteen days. The surface was then tar sprayed and "chipped" with whinstone chippings [⅜-in. to ¼-in. gauge]. No transverse expansion joints were provided, but ½-in. white pine boards were laid against the kerbs, which boards were intended to be afterwards removed so as to provide expansion joints, but there was difficulty in getting them out and consequently they were left in.

By far the most interesting experiment, however, in the construction of concrete roads in this country, was that on a portion of a road near Gravesend in Kent, which was commenced in the late autumn of 1914, and was practically doomed to failure from various causes which will be explained.

Kent Trials.—The following is a copy of the specification :—

(1) *Existing Surface.*—The existing surface shall be scarified to such depths and levels as shall be determined by the county surveyor.

The surface shall then be rolled and thoroughly consolidated to an even contour, the surface to be left sufficiently rough to make a good key for the concrete. Should any weak places show themselves, they shall be excavated and filled up with hard stone of a large gauge, and made thoroughly sound.

(2) *Cross-fall.*—The finished surface thus obtained shall have a cross-fall of 1 in 50.

(3) *Kerbs.*—Granite kerbs shall be laid in accordance with the specifications, etc., of the Kent county surveyor. Provision shall be made for a longitudinal expansion joint adjoining the kerb, which is referred to under "Expansion Joints" later.

(4) *Concrete.*—The concrete shall consist of 6 parts of crushed ballast and sand as hereinafter described, and 1 part of best Portland cement.

(5) *Ballast.—The ballast shall be all thoroughly washed and screened*, great care being taken to entirely eliminate all foreign

matter, such as clay or decaying vegetable matter, and shall consist of the following sizes thoroughly incorporated:—

25 per cent.	material	passing	through a	1-in.	screen	and	retained on	½-in.
25 ,,	,,	,,	,,	¾-in.	,,	,,	,,	⅜-in.
25 ,,	,,	,,	,,	¼-in.	,,	,,	,,	a 22 screen.
25 ,,	clean, sharp sand, all through $\frac{3}{16}$-in. screen.							

The crushed ballast and sand is to conform strictly to the sample kept at the office of the Kent county surveyor.

(6) *Cement.*—The cement is to be supplied by a British manufacturer complying with the B.S.S. for slow-setting cement.

(7) *Mixing.*—The concrete shall be mixed in a batch concrete mixer of an approved type.

The ballast and sand shall first be placed in the mixer and thoroughly mixed dry. The Portland cement shall then be added, and the whole again revolved a sufficient number of times to ensure a thorough incorporation. The necessary water to be then added, and again thoroughly mixed.

(8) *Consistency.*—Great care shall be taken to prevent an excess of water being used in the process of mixing. The consistency of the concrete when ready for laying should be such as to require but little tamping after being placed in position, but not so wet as to cause the separation of the mortar from the aggregate during handling and laying. The concrete when mixed shall be of a plastic consistency.

(9) *Spaces for Expansion Joints.*—Provision for transverse expansion joints shall be made in the concrete at a distance of every 25 ft., and for longitudinal expansion joints alongside the kerb before the concrete is laid by the placing of ½-in. by 7-in. [or 9-in.] wrought boards of convenient length and slightly greased with a hard lubricating grease, the same to be withdrawn when the concrete has sufficiently set to allow of their being removed without the arrises being destroyed.

(10) *Transverse Expansion Joint.*—Creosoted deal slips ½ in. thick, 5 ins. deep, and 9 ins. long to be laid on a bed of sand. The slips to be jointed ⅛ in. above the surface of the concrete and grouted with pitch and creosoted oil applied at boiling heat.

(11) *Watering Old Surface of Road prior to Laying Concrete.*—The surface of the road on which the concrete is to be laid shall be swept clean of all deleterious matter and thoroughly watered prior to any concrete being placed on same.

(12) *Laying Concrete.*—One half of the road will be closed to traffic and surfaced with concrete at one time.

The concrete shall be spread rapidly in successive batches to a consolidated depth of 6 ins. over one half of the width of the road, making each section between the expansion joints one complete mass.

The edge of the concrete in the centre of the road shall be left with a rough vertical edge and reinforced with a 3 ft. width of Expanded Metal Company's No. 61 3-in. diamond mesh expanded steel. The sheet to be bedded in the concrete 2 ins. from the surface and to extend 1 ft. 6 ins. on either side of the centre joint.

When joining the two halves of the road together, the edge should be thoroughly swept, watered, and painted with a thin coat of neat cement and water in equal proportions. The concrete shall then be applied immediately. Every endeavour should be made to avoid longitudinal joints showing when the road is completed. The concrete adjoining the expansion joints shall receive very careful attention, and shall be packed up close to the boards to ensure the density of the concrete.

(13) *Tamping.*—The concrete shall be brought to the required surface as described hereafter. Retamping after the concrete has assumed its initial set will not be permitted.

In no case shall a greater time than twenty minutes elapse between the deposition of two successive batches.

(14) *Finishing Surface.*—(*a*) As soon as the concrete is laid the surface shall be struck off by means of a template resting on one kerb and one longitudinal screed, the template being moved over the surface with a combined longitudinal and transverse motion. Any excess of material accumulating in front of the template shall be uniformly distributed over the surface of the pavement, except when near the expansion joints, when the excess material shall be removed; (*b*) the

finished surface shall conform to the sample surface kept on the works and shall provide a sufficiently rough surface to give a good foothold.

(15) *Filler for Longitudinal Expansion Joint.*—The longitudinal expansion joint shall be filled flush with the finished surface of the concrete with commercial soft pitch, Road Board Specification, No. 6.

(16) *Protection of Finished Surface.*—When the concrete has set, the surface shall be covered evenly with a coat of clean wet sand laid to a depth of 2 ins., which shall not be moved until a period of eight days has expired. The sand shall be kept wet during the whole time it remains on the concrete in order to prevent the concrete drying out too rapidly.

This road was not a success due in great measure to the fact that the concrete was too weak, and this was confirmed by the excellent result obtained from a portion of the road which was laid with 3 parts of "ballast" to 1 of Portland cement, instead of the weaker proportion specified. The traffic on this road was about 1,000 tons a day, consisting chiefly of motor omnibuses and quick-running commercial motors of great weight. The carriage way is only 21 ft. in width; the traffic could not be diverted, and the road had to be constructed in half-widths at a time, so that the whole traffic was concentrated on the newly formed concrete on one side on a width of only about 10 ft., a trial of the greatest severity which no green concrete could possibly stand unless of the most solid and well-made construction. The time of year for such construction was wrong, and the extreme wet and changes of temperature minimised any hopes of success. As an object lesson in concrete road construction, this road has the advantage over other roads of similar construction, inasmuch as it clearly shows the reasons for failure, as the portion which was constructed, on better lines, shows how a concrete road can be made to stand in excellent condition by the side of one that is a failure.

It is evident, however, from the successes which have followed this form of road construction in America and Canada, that a good concrete road can be made, if sufficient care and supervision are exercised during construction.

Points to be Considered.—The following summary of points are consequently suggested as being worthy of consideration before preparing a specification of the manner in which the work should be carried out:—

(1) *The Sub-base or Foundation.*—This should be well drained, and formed and consolidated with a 10-ton roller, all inequalities, or depressions, having previously been made good. The surface of this sub-base, instead of being left rough, should be left as smooth as possible, in order to prevent friction between the concrete and the sub-base.

(2) *Materials.*—It is almost needless to say that the cement must be of the best quality, and the aggregates selected, broken and blended, with care and discrimination.

(3) *Proportions.*—These are of course very important, as the object to be attained in good concrete is to have as few voids as possible, in order to prevent the admission of water, which is one of the chief causes of subsequent expansion and consequent cracking from internal stresses.[1]

[1] Mr. H. C. Johnson at a recent meeting of the Concrete Institute, read a paper on "A Method of Proportioning Materials for Concrete," in which he gave some very valuable hints as to the right proportions of the cement and various aggregates, the result of a series of tests which he had made. His conclusions were as follows:—

(1) The 1 : 2 : 4 method of proportioning should be considered obsolete, since no two 1 : 2 : 4 concretes contain the same percentage of cement, neither does it allow the majority of materials to produce their best values.

(2) An actual test of the materials it is proposed to use should be made, introducing the percentage of cement required for the particular purpose the concrete is for, and finding the ratio of small to large aggregate accurately by this means.

(3) Other things equal, the percentage of cement closely governs the strength. Other things equal, the larger the aggregate the stronger the concrete.

(4) Previous tests proved that washing the average aggregate carefully will allow 30-40 per cent. higher strength in a hand mix, but only about 15-25 per cent. in a machine mix. This is always excepting really dirty material.

(5) Using a mixer and giving two to three minutes for mixing will give a concrete, other things equal, about 50-75 per cent. stronger.

(6) For equal working consistency and equal cement gravel concrete is as strong as stone concrete.

(7) Gravel passing same screens as stone always has less voids than the stone.

(4) *Mixing.*—This should not be done in a haphazard manner; everything should be measured, including the water. If mixed by hand, the aggregate and cement should be turned over three times in a dry state and three times in a wet state. It is of course best to mix it in a batch box, and the result of numerous tests has shown that the strength of eight-day old concrete was greatest when the batch was mixed in a box for 1½ minutes, with 20 revolutions of the machine during that period.

Each batch of concrete should be in what is known as a "quakey" condition when laid *in situ.* If too wet the heavier portions are liable to sink, leaving a thin face of mortar on the top which tends to peel off under the traffic.

(5) *Placing Concrete in situ.*—The American engineers have systematised the organisation for this so as to save labour and cost. The principal point is, however, that directly a batch is made it should be immediately placed in position. Very little ramming is required, as this only brings the water and fine portions of the aggregate to the surface.

(6) *Finishing the Surface.*—The American engineers are somewhat divided as to how the surface should be finished off, but most of them are of opinion that ordinary smoothing with a spade, or even "floating" is undesirable, and that the surface should be finished off with a long screed or template, curved to the proper contour of the surface, which screed is

(8) Fine sand concrete has smaller weight per cubic foot than coarse sand concrete.

(9) Fine sand plus large aggregate [without cement] gives smaller volume than coarse. Fine sand plus large aggregate [with cement] gives larger volume than coarse.

(10) Fine sand concrete is easier worked than coarse sand concrete for equal amounts of sand.

(11) The finer the aggregate the more deleterious material and air it carries with it into the concrete.

(12) The finer the sand the less should be used.

(13) 30-40 per cent. higher strengths are obtained with 3·16-in. cubes than with 6-in. cubes.

(14) Small cubes are more uncertain and inconsistent in the strength values than larger cubes.

(15) In the future, and in order that tests at various places shall be truly comparative, two things are required: (*a*) the percentage of cement in the concrete; (*b*) the strength of the cement in mortar tension or mortar compression.

dragged along the surface by men—at each end—who gave it a slight zig-zag motion in order to produce a somewhat roughened or serrated surface. In some cases, a length of old machine-belting is dragged along the surface; in others, a brush or broom is employed, though in this case there is the disadvantage that the men leave depressions where they stand or walk.

It is evident that the long template must leave a very even surface; this cannot be done by ordinary floating, where the eye alone is the judge of a smooth surface, and consequently depressions may occur which will afterwards hold water.

In whatever manner the surface is finished, it is necessary to cover it with sand or other protection, which should be kept thoroughly damp for several days, as changes of temperature on green concrete are liable to cause it to crack.[1]

(7) *Tar Spraying and Gritting the Surface.*—These operations are really a matter of opinion. It is claimed that they preserve the surface and prevent abrasion. They are no doubt useful where trenches have been cut and repaired, as they hide the otherwise unsightly joints. They certainly ought to make the surface less harsh, and they do prevent the rising of dust caused by attrition. They also remove the white appearance of a concrete road. It is doubtful if "gritting" serves any useful purpose, but tar spraying covers all the above points. A sprinkling of fine sand is better than "chippings" or "grit".

(8) *Period of Diversion of Traffic.*—There are somewhat different opinions as to the time which should be allowed for the green concrete to set and harden before the traffic is allowed on it. It depends considerably on the condition of the weather, but, as a rule, the traffic should not be allowed on a newly constructed concrete road under a three weeks' period, or even longer where practicable.

[1] Recent experiments, carried out in the University of Minnesota, showed that a beam of concrete 100 ft. in length shrank nearly an inch in a purposely heated building. It was also found that swelling or expansion is caused by moisture. As a further result of these experiments, it was proved that even mature concrete expands when moisture enters the pores and comes in contact with unhydrated particles of cement.

(9) *The Prevention of Cracks.*—Cracks are one of the "bug-bears" of all concrete slabs laid *in situ* and are due to various causes—sometimes from complex internal stresses, especially if dried too quickly. Water is, of course, necessary to hydrate the more inactive particles of cement, and to keep the concrete expanded. When concrete is green, a drop in the temperature will cause it to crack. These changes of temperature keep the concrete moving on its sub-base, but if the friction between them is excessive the concrete cracks. It is also subject to bending stresses under heavy loads, aggravated by an unequal settlement of the sub-base, and sometimes by movements of the sub-base, due to moisture or changes of temperature. Expansion joints are inserted to prevent this cracking, but, with the exception of the longitudinal expansion joint alongside the kerbs, the necessity for transverse joints is decried by some engineers, who state that, unless very narrow and well filled, their arrises chip, and thus commencement of serious injury is set up. It has been suggested that if these transverse joints are left they should be spaced in the proportion of one transverse joint for every three times the width of road, but no valid reasons are given for this dictum. If alternate bays of concrete are laid, and allowed to set, before the intervening bays are constructed, this helps to prevent cracking, as the extent of green concrete is thus reduced, and this practice renders any special expansion joints unnecessary.

It is stated that, after recent and careful experiments by the Public Roads Bureau of the United States Department of Agriculture, it is found that the addition of about 10 per cent. of heavy mineral oil renders the concrete less absorbent of moisture, and that this addition does not affect the tensile strength, but prevents its being affected by the disintegrating effects of alkalies. I am not aware whether this has been tried in this country, nor can I express any opinion as to the merits or otherwise of such an addition, but I understand that it has received the approval of Mr. Logan W. Page, the well-known American authority on road building.

It is contended that a slight reinforcement of the concrete tends to prevent cracking, and this should certainly have a beneficial result, besides making the concrete more resilient.

(10) *Cutting Trenches and Repairs.*—It is often contended that a concrete road, especially if reinforced, is difficult and expensive to open up for laying sewers, drains, gas or water pipes, etc., and that when the roads are reinstated there are ugly joints left which take a long time to obliterate. There is some truth in this, and the following extract from an American engineer's recent letter on this point will be of interest:—

"It must be admitted, of course, that considerably more care must be exercised in repairing concrete than probably in any other class of road. The practice here is to refill the hole with the material of the sub-grade, putting in about 4 ins. at a time, and thoroughly tamping same without the use of water. If water is used, it is felt there is bound to be subsidence later. This sub-grade, after having been put in, is covered up and allowed about another week to consolidate, after which the concrete is replaced, using wire-mesh reinforcing, as it has been found this tends to make a much better job than straight concrete. The repaired concrete is then covered up in some way, the material used being dependent, of course, on the size of the hole. Sometimes, if the latter is small, a barrel is used; or, if it is larger, ordinary shiplap is placed over the green concrete, and some rough sacking or tarpaulin added. The main thing is to keep traffic off it for at least twenty-eight days. If the concrete is not allowed to cure properly, there will, of course, be trouble.

"As I stated before, this practice of repairing concrete has been done successfully on the coast, and I see no reason at all why conditions should be any different on your side.

"As I believe you tar some of your concrete roads, repaired patches could be done with asphalt, if it was impossible to keep traffic off for the period of twenty-eight days. As the colour of the road would be black in any case, asphalt would hardly be distinguishable from concrete. I feel, however, that in nine cases out of ten, if every one concerned was reasonable, concrete patches could be put in any road, and adequately protected against traffic."

In Macon, Georgia, it has been stated that the gas company opened a concrete street in 122 different places, and that in the year following it was almost impossible to detect where these openings had been made. "The surface was simply treated with tarvia, one gallon at 250° F. to every three square yards of road surface, and then sand sprinkling did all that was necessary, and made the road dustless and noiseless—as good as asphalt and much less expensive."

There is unquestionably some little difficulty about these openings, but if provision is made for all necessary repairs to mains and service pipes to be carried out before a new road is constructed, the necessity for re-opening the road should be greatly reduced.

Bearing the above points in mind, and in view of the necessity, so often repeated, that in the construction of this description of road the greatest care and supervision are necessary, the following "cast-iron" specification is put forward, which is trusted may at least form the basis for a specification, altered, amended, or extended, in such a manner as may meet the exigencies of any special case or locality.

Suggested Model Specification for the Construction of a Concrete Road:—

(1) *Cement.*—The cement shall be supplied by a British manufacturer of repute, and shall comply with the requirements of the British standard specification for cement in force for the time being. It shall be of the "slow-setting" quality, as defined in that specification. Conditions as to testing, delivery, and storage shall be agreed between the vendor and purchaser.

(2) *Aggregates.*—Great care shall be taken in the selection of the aggregates. The actual materials to be used must depend upon local circumstances, subject to the following limitations:—

"No natural deposits of sand and gravel shall be used without washing, screening, and grading to comply with the conditions hereinafter laid down.

"If crushed stone is used it shall be screened, graded, and, if necessary, washed, to comply with the conditions hereinafter laid down.

"No aggregate shall be used which is not hard and tough, or which is laminated, or which, upon crushing, breaks down into flat or elongated particles. Soft or porous materials, such as broken brick, breeze, etc., shall be prohibited.

"All aggregates used shall be clean and free from clay, dust, vegetable, and other foreign matter. Care shall be taken that the aggregate is not contaminated with mud, etc., after delivery to the site of the work.

"For one-course roads no aggregate shall be used which will not pass through a screen having square openings of 1 in., but for two-course roads the bottom course may contain aggregate the largest stones in which will pass through a $1\frac{1}{2}$-in. square opening. None of the coarse material shall pass through a $\frac{1}{4}$-in. square opening. The grading from the maximum to the minimum sizes shall be regular, and no material shall be used which contains a large proportion of stones of approximately one size.

"Sand or fine material shall all pass through a $\frac{1}{4}$-in. square opening, but not more than 10 per cent. by weight shall pass a sieve having 50 meshes per lineal inch. The grading from the maximum to the minimum sizes shall be regular, and no material shall be used which contains a large proportion of particles of approximately one size.

"Representative samples of the approved coarse material and sand shall be retained by the engineer in charge of the work, and all deliveries shall be required to conform strictly to such samples."

(3) *Concrete.*—The average compression resistance of not less than three test pieces of the concrete shall not be less than will comply with the following formulæ:—

When 4 weeks old—C. 1 = 2,800—200 V. and
,, 13 ,, —C. 3 = 3,600—200 V., where
C. 1 and C. 3 = compression resistance in lb. per square inch.
V. = Volume of sand and coarse material per volume of cement.

For determining the compression resistance, tests shall be made on cubes or cylinders of not less than 6 ins. each way. The preparation, setting, and maturing of the test pieces shall, as far as possible, conform to the conditions that will obtain in the actual execution of the work, provided that care be taken to see that the conditions for all test pieces are as uniform as practicable, and that none of them are exposed to frost during setting and maturing. The compression resistance of any test piece which gives such a low result as to indicate a faulty specimen shall be eliminated in arriving at the average of the results for any test.

(4) *Water.*—The water shall be fresh and clean, and shall be taken from a public drinking water supply or from other source of known purity.

(5) *Reinforcement.*—All metal for reinforcement shall be free from oil, paint, excessive rust, or coatings of any character which will tend to destroy the bond with the concrete. The metal shall develop an ultimate tensile strength of not less than 60,000 lbs. per square inch, and withstand bending when cold 180° around one diameter and straighten without fracture.

(6) *Joint-filler.*—Joint-filler must be an elastic waterproof material, which will not lose these properties under extremes of weather conditions.

(7) *Foundation.*—The preparation of the foundation will necessarily vary with local conditions, and must be determined by the engineer in charge of the work. Any necessary embankments or fills shall be executed to the satisfaction of the engineer, and shall be thoroughly consolidated, so that there is no possibility of settlement at any point. Any soft or weak places must be excavated and filled up with hard stone or other suitable material, so as to obtain solidity equal to the remainder of the surface. The surface will be finally rolled to the required contour with a roller of not less than 10 tons in weight, and the surface left as smooth as possible. The surface thus prepared shall have a cross-fall of 1 in 50.

It should be noted that the use of concrete for the road cannot be assumed to do away with the necessity for a good and even foundation over the whole surface.

When the road is not supported by kerbing on either side, a channel not less than 6 ins. wide and 4 ins. deep shall be dug longitudinally, immediately inside the edge of the prepared base, so that the concrete when placed shall act as a support to the haunches of the road.

Immediately before the concrete is put into place, the prepared surface shall be swept clean of all dust and dirt and thoroughly watered.

(8) *Drainage.*—Where local conditions require, a suitable drainage system shall be provided to the satisfaction of the engineer.

(9) *Proportions.*—The coarse material and sand shall be used by volume, in such proportions, one to the other, as are found by trial with several mixtures of the same total quantity measured separately, but of varying proportions, to give the least volume of concrete when mixed with the prescribed quantity of cement and tamped into a mould of known capacity.

For one-course roads not more than 5 parts of coarse and fine aggregate, mixed as provided, to 1 of cement, shall be used. For two-course roads not more than 8 parts of coarse and fine aggregate, mixed as provided, to 1 of cement, shall be used for the lower course, and not more than 3 parts of fine aggregate to 1 of cement for the upper or surface course. One-course roads shall only be laid in places where severe traffic conditions are not likely to be met with, unless made with concrete containing not more than 3 parts of aggregate to 1 of cement.

(10) *Measuring the Materials.*—The method of measuring the materials for the concrete, including water, shall be one which will ensure uniform proportions at all times. The cement shall be taken by weight on the basis that 90 lbs. is equivalent to a volume of 1 cubic foot.

(11) *Mixing.*—The concrete shall be mixed in a batch concrete mixer of an approved type. The materials shall first be mixed dry, the mixing being continued until the materials are uniformly distributed, and the mass is uniform in colour. The water shall then be added and the ingredients again mixed until they are homogeneous and plastic throughout. The drum shall be completely emptied after mixing each batch.

(12) *Consistency.*—The quantity of water to be added to

the concrete shall be such as to secure a plastic mixture which can be easily worked, and so that only light tamping shall be necessary to consolidate when placed in position. Care shall be taken to prevent an excessive amount of water being used, and the concrete shall not be so sloppy as to cause a separation of the coarse aggregate from the mortar during handling and laying.

Any concrete which has partially set before being placed in position shall not be used. To avoid waste from this cause, all concrete which is mixed ready for placing in position immediately before the dinner hour or other stoppage of the work shall be placed and finished before stopping. Under all circumstances, as little time as possible shall elapse between the mixing of the concrete and placing and finishing.

(13) *Weather Conditions.*—So far as is practicable, all work shall be done during the summer months, but in no case shall concrete roads be laid in the winter months, except as a matter of urgency; and under no circumstances shall concrete be mixed and deposited when the thermometer is below 39° F.

The concrete shall be deposited over the whole width of the road at one and the same time, except in cases where it is impossible to divert the traffic for the time being, and shall be deposited in alternate bays of not more than 50 ft. in length. The end of each bay shall be supported by a wooden or metal form sufficiently strong and properly supported to resist straining out of shape under the pressure of the concrete. All mortar and dirt shall be removed from forms which have been previously used, and the forms shall be wetted thoroughly before any concrete is deposited against them. The intervening bay shall be filled in when those on each side are set sufficiently hard to permit of the removal of the forms without damage to the edges. If considered necessary, joints filled with material complying with paragraph 6 may be provided between the bays, but shall not exceed ½ in. in thickness. Longitudinal joints, similarly filled, may also be provided alongside the kerb or channelling [if any], if desired.

(14) *Thickness.*—The total thickness of concrete for both one and two-course roads shall not be less than 6 ins. when

tamped and struck off to the finished surface. The surface course of two-course roads shall be approximately 2 ins. thick.

When a two-course road is being laid the upper course or wearing surface shall be spread on the lower course immediately after the latter is deposited and before it has begun to set.

(15) *Surface.*—The wearing surface shall be struck off to the finished contour, by means of a template which shall be drawn over the concrete with a combined longitudinal and transverse motion, so as to produce a slightly serrated surface, free from depressions, or inequalities of any kind, and this surface shall not afterwards be disturbed by floating off, or in any other way. The finished surface shall have a cross-fall of 1 in 60, and shall not vary more than $\frac{1}{4}$ in. from the true shape.

No cessation of work of more than an hour's duration shall be permitted, except at the end of a completed bay.

In cases where it is impossible to divert the traffic and the concrete has to be laid on one-half of the road at a time, the edge of the concrete in the centre of the road shall be left with a rough vertical edge, and immediately before filling in the concrete for the second half this edge should be thoroughly swept, watered, and painted with a thin coat of neat cement and water in equal proportions. The concrete shall then be applied immediately.

(16) *Reinforcement.*—When considered desirable, the concrete shall be reinforced with steel-mesh reinforcement of a type approved by the engineer. The area of the reinforcing metal shall be equivalent to 0·05 square inch per foot of length or width of the concrete. In cases where joints as described in paragraph 6 are provided, the reinforcement shall be carried to within 2 ins. of the joints, but shall not be carried across them, and all joints of the mesh reinforcement shall overlap at least 6 ins.

(17) *Watering Surface.*—The surface of the concrete shall be sprayed with water as soon as it has sufficiently hardened to withstand pitting, and shall be kept wet until covered as hereinafter provided.

As soon afterwards as it can be done without damaging the surface, the pavement shall be covered with not less than 2 ins. of wet sand or other material which will afford equally good protection. This shall be kept thoroughly wet during the whole time it remains on the concrete, and shall not be removed until at least ten days after placing.

When sunshine, a drying wind, or other conditions make it desirable, in the opinion of the surveyor, the freshly laid concrete shall be protected by canvas laid on a wooden framing or other covering until set sufficiently to be watered and protected as prescribed.

(18) *Opening to Traffic.* — Under the most favourable weather conditions, the concrete road shall not be opened to traffic until at least twenty-one days after it is laid, and when the weather is unpropitious this period shall be increased for such additional time as may be necessary in the opinion of the engineer.

Where the road is constructed in two halves owing to the impossibility of diverting the traffic, the traffic should not be concentrated on to the first half which has been concreted until at least thirty-five days after completion, or longer where weather or other conditions make it advisable in the opinion of the engineer.

The above-suggested lines on which a specification for this class of work should be prepared, may appear to be somewhat drastic and severe, but it is evident that unless every batch of concrete placed *in situ* is of equal quality, and the best that can be made, the chances of success are very remote.

With regard to cost. The few examples of this description of road construction would be no criterion or guide. The cost of labour and haulage has enormously increased since the outbreak of war in 1914, and the price of materials have proportionately advanced. The costs in America and Canada would be no help, as ruling prices are not the same there as here. But the American and Canadian road engineers have long ago realised that the cost of construction of a concrete road can be materially reduced by employing all the machinery and plant possible, eliminating labour to a minimum, and so organising the whole of the work that there shall be as little "leakage" as possible. This includes carrying out the work on the largest possible scale, the bigger the area, the smaller the cost per square yard, and the better the work. It would appear therefore that with the trials which have been made in this country that the areas dealt with have been far too small, and the methods adopted for the work were far too "elastic". It is to be hoped that before long a proper trial, on more rigid lines, and on a larger scale, may be attempted.

By far the most interesting example of reinforced concrete roads in this country, which only came to the notice of the author when the MSS. was on the eve of going to the publishers, is to be found in the Royal Albert and Victoria Dock extension, where work of this description was started in 1917 and is still in progress. Already about 17,000 square yards of concrete roads have been constructed, and a short length has already been subjected to very severe and heavy traffic.

The total thickness of the concrete road as laid is 9 ins., including a top coat or wearing crust 2 ins. thick. The subsoil was of a very bad character, entirely made ground from dock dredgings—a more unstable foundation would be hard to find, and under such circumstances the concrete necessarily required reinforcement, both at the top and the bottom to provide for the tensional contra-flexure stresses imposed by a rolling load; it was also provided that the top and bottom layers should be connected together by vertical reinforcement to provide for the shear or diagonal tension stresses.

Practically all the roads are rafts, and the system of reinforcement adopted was to meet this form of construction. This was achieved by a specially designed pyramidal framework consisting of $\frac{3}{16}$-in. steel bars made up of various straight lengths interlocked with bent or "zig-zag" bars.

The ingenious yet simple manner in which this reinforcement was accomplished would be too lengthy to describe, but the simple apparatus for bending the bars and interlocking them, and the other appliances, were designed and patented by Mr. J. H. Walker, Resident Engineer for the Port of London Authority. The proportions of the concrete and the methods of mixing and constructing the road may shortly be described as follows:—

The lower 7 ins. consists of 6 of Thames ballast to 1 of Portland cement, the top or wearing crust of 2 of $\frac{3}{4}$-in. broken shingle to 1 of Portland cement. A portion of the roads were constructed with $\frac{3}{4}$-in. broken shingle and other portions $\frac{3}{8}$-in. shingle, according to the supply that could be obtained.

The construction of the road is as follows: after the road bed had been excavated and graded, the reinforcement was laid thereon, the bottom 2 ins. of concrete was laid thereon, and the reinforcement lifted through it, by hooked bars, so that it rested on the concrete. The remaining 5 ins. of the bottom 7-in. coat was then deposited. The top 2-in. coat of 2 to 1 was then placed in position and screeded up by a specially constructed screed worked by two men which brought the surface to the actual level and contour required.

A special feature in the making of these roads is the machine for mixing, laying, and screeding the concrete, which may shortly be described as follows:—

It consists of a light timber framework structure, completely spanning the whole width of the road, and carried either side on a bogie mounted on rails. One bogie mounted on a 4 ft. $8\frac{1}{2}$ in. gauge truck [ordinary railway gauge] carries an electrically driven Ransome-Vermehr half cubic yard Concrete Mixer, and also an electric motor driving a pair of friction winches. The bogie on the other side of the road is mounted on a 24-in. gauge truck and carries the other end of the framework. This framework is covered over with tarpaulins, and can be easily lighted or heated so that work can proceed, if necessary, day and night and also in frosty weather.

To the underside of the ridge of the framework structure is attached a very novel cable-way arrangement, by means of which the concrete skep is conveyed from the discharging shute of the concrete mixer to any part of the road under the tarpaulin "tent". Friction winches actuate the two ropes of this gravity cable-way system.

By this arrangement the labour of only one man is required to actuate these ropes and to deposit the concrete on any part of the area under the "tent".

The concrete surface is screeded off by a new form of double-handled screed board, worked by two men standing on boards opposite each other, laid transversely across the "tent". The roads are 30 ft. wide and are screeded in three strips. When screeding the crown or centre strip, each end of the screeding board rests on two fixed angles carried transversely across the base of the tent, i.e. the angles are parallel to the longitudinal axis of the road. These angles are easily adjusted and fixed to the correct height to enable the screed to automatically strike off the surface to the correct level. The gutters on each side are screeded in a similar manner with the exception that the gutter end of the screed rests on a board fixed to pegs in the ground, the board being graded to the levels required for the gutters.

The men employed in this work, were as follows:—

1 man dealing with the cement.
4 men filling the elevating hopper.
1 man driving the mixer.
1 ,, working the cable winch.
3 men levelling off the concrete on the road.
2 ,, attending to gutter screed boards.
1 ganger.

A total of 13 men, who were thus able to mix and lay *in situ* 27½ cubic yards of concrete a day, which was equal to 99 square yards of finished road per working day of 9 hours.

The author has had an opportunity of inspecting the work whilst in operation and of examining the finished roads. He was greatly struck with the methods employed for their construction and their excellent appearance. There were absolutely no cracks, although no expansion joints of any kind are provided. He observed the traffic on a portion of one of the roads which was evidently very severe and the surface showed no signs of wear. It is evident that these roads are being constructed on skilful lines and that they will meet the very exceptional circumstances which exist in the locality.

CHAPTER X.

SLIPPERY STREETS AND CONCLUSION.

ALTHOUGH the question of a slippery surface of a street is not quite of so much importance as when horses alone moved our vehicles, there are still a large number of horse-drawn vehicles, and also the self-propelled vehicle is not altogether without some desire to skid, or waltz, on a very slippery road surface.

Causes of Skidding.—In the early "motor" days, viz. in 1906, a Select Committee termed skidding or side-slip one of the greatest dangers in the use of all self-propelled vehicles with rubber tyres, and that the causes were mainly attributable to greasy or slippery road surfaces, and the mechanical action of the differential gear in propelling the driving wheels unequally under certain circumstances, that this was aided by the needlessly high camber of many roads[1] and by their improperly kept surfaces.

They also drew attention to bad driving contributing in large measure to the skidding of a motor vehicle, which was quite correct, as it is well known that skidding or slipping can in large measure be prevented in the hands of a skilful driver, even on a very slippery road. It is evident, for instance, that if the brake is too suddenly applied on a road that is at all slippery, "something will happen".

It would, however, be approaching the "millennium" if motor vehicles and road surfaces could both be made "Fool Proof".

Non-skidding Devices. — To furnish all self-propelled vehicles with some non-skidding device on the tyres of their

[1] The author has already dealt with this question of excessive camber, *vide* p. 37.

wheels would probably mean excessive road punishment and is to be deprecated.

To make the surface of a road, or street, absolutely non-slippery under all climatic conditions is not an easy matter, but there is no doubt that some classes of road surfaces are worse offenders in this respect than others.

Slippery Road Surfaces.—It is a little difficult to make a list of such types in their order of slipperiness,[1] but the author attempts to do so in the following list, though the order may be open to some criticism. He has purposely omitted ordinary unsurfaced water-bound macadam roads which are not slippery except in cases of frost, or from a greasy mud on their surface which sometimes appears, and should of course be cleared off at once.

Table of street types which are more or less slippery:—

(1) Natural rock compressed asphalt.

(2) Water-bound macadam with its surface tarred, but not sanded or gritted.

(3) Bituminous-bound macadam [tar macadam, tar slag, and the like].[2]

(4) Road carpets of bituminous material and very fine aggregate.

(5) Wood pavement.

(6) Granite setts.

None of the above-mentioned surfaces are "naturally" slippery when thoroughly dry or thoroughly wet, except from causes which will be explained hereafter, but under certain weather conditions they may become almost dangerously

[1] The word "slipperiness" is a very clumsy word, but there is nothing in our vocabulary which expresses this "quality" in any other way, nor is there any word which conveys the meaning of the reverse of slippery except "un-slippery". It is a pity that some better and more concise words cannot be invented.

[2] At a recent meeting of a certain County Horse Owners' and Cattle Protection Association, the following resolution was unanimously passed: "That, in view of the dangerous state of certain roads for horse, cattle, and vehicular traffic, this association has decided to approach the Road Board to urge upon them the necessity of making such roads safe for such traffic, and, further, to ask them not to sanction any scheme submitted to them for the alteration of the surface of any other existing road, unless proper and adequate provision has been made to make the surface of such roads at least as safe as the present surface is for horses, vehicles, and cattle".

slippery and have to be sprinkled with gravel, ballast, or chippings. This treatment, however, is not possible in outlying parts where neither the material or the necessary labour are available.

Benefit of Thorough Cleansing of Surfaces.—It is hardly necessary to point out that systematic cleansing of all road surfaces is most desirable if slipperiness is to be avoided, but this is a question of labour and expense. The alternative, which requires less labour, is that of frequent washing of the surface with water, under pressure, from a hose, but this is only available where there are water mains and hydrants. There is also the difficulty sometimes met with that under the particular Water Act of the district, the use of water for such a purpose is not allowed. Washing is undoubtedly the best remedy, although with sudden changes in the weather conditions even a well-cleansed street will become, almost suddenly, greasy or slippery, when sanding or gritting has to be applied at once to the surface.

Sprinkling with Gravel or Chippings.—Unfortunately, some chippings or gravels are injurious to pneumatic rubber tyres, and complaints are frequently made by motorists and cyclists as to their tyres being cut from this practice. Sprinkling with sand or gravel, etc., cannot be abandoned, but care should be exercised in the selection of the material; it should not be too large, and should consist of chippings, or gravel, capable of passing through a $\frac{3}{8}$-in. ring, and so far as possible be devoid of sharp edges or arrises.[1]

Oil and Grease on Roads.—Another cause of temporary local slipperiness arises from the oil and grease which is allowed to drop on to the surface of a carriage way from self-propelled vehicles. This is a rather growing evil in towns where these vehicles are often allowed to stand for some time in the streets.

[1] In the year 1911 at a special conference between the Institution of Municipal and County Engineers and the Roads Improvement Association, the following resolution was passed: "That this conference strongly urges the local authorities in the metropolis to use for the gritting of road surfaces a material of as small a size as circumstances warrant".

The author understands that there is legislation to prevent this, but he ventures to think that it is not very strictly enforced.

Excessive Camber.—But one of the most contributory causes of slippery streets and roads is the excessive camber frequently given to the surfaces of imperviously paved, or protected, carriage ways. As he has already pointed out, the object of camber is merely to throw off the rain falling on the surface, and much less camber is required on a smooth surface than that which is necessary for a rougher description of surface such as ordinary water-bound macadam.

It would of course be impracticable to alter the camber of most of our existing streets and roads, but when re-surfacing is being contemplated the point should be considered. It can only be hoped and believed that road engineers and surveyors are now alive to the fact that excessive camber under the more modern methods of road construction is no longer required.

Scientific Inquiry into Skidding.—At a joint conference held some years ago between "road makers and road users," several papers were read on the question of the skidding of motor vehicles, and Mr. E. Shrapnell Smith contributed a valuable paper on the subject, from which the following extracts are taken:—

He commences by describing some tests he had made to determine the coefficient of friction for loaded rubber-shod driving wheels [locked] on dry macadam, which proved as high as 0·58 [45 cwts. draw-bar pull with an axle weight of 77 cwts.]. This showed that the limiting angle of friction is 30°, equivalent to a gradient of 1 in 1·72.

He then gives the following table of coefficients at limiting angles of friction:—

Materials.	Condition of Surfaces.	Coefficients.	Limiting Angles.
			Degrees.
[1] Wood on wood . .	Dry	0·3 to 0·5	17 to 27
[1] ,, ,, ,, . .	Soaped	0·1 ,, 0·2	6 ,, 12
[1] ,, ,, ,, . .	Greased	0·02 ,, 0·1	1½ ,, 6
[1] Metal on wood . .	Dry	0·2 ,, 0·6	12 ,, 30
[1] ,, ,, metal . .	,,	0·15 ,, 0·3	9 ,, 17
[2] ,, ,, ,, .	Lubricated with tallow	0·11	6
[1] Leather on wood . .	Dry	0·5	27
[1] ,, ,, metal . .	,,	0·56	29
[1] ,, ,, ,, . .	Wet	0·36	20
[1] ,, ,, ,, . .	Greased	0·23	13
[1] ,, ,, ,, . .	Oiled	0·15	8½
[3] Rubber on macadam .	Dry	0·58	30
[4] ,, ,, asphalt .	,,	0·60	31

The above table shows a marked and proportionate decrease in the coefficient of friction between any two of the bodies subjected to test, as the condition of their surfaces becomes more and more removed from the dry and the clean conditions.

From this table he "deduced" the following table to show the "approximate scale showing the tendency of the smooth rubber-tyred wheels of a motor bus to skid as adhesion is diminished":—

Road Surface.	Coefficient of Friction.	Limiting Angle of Friction.	Power of Holding the Road.
		Degrees.	
Dry asphalt . . .	0·60	31	100
,, macadam . .	0·58	30	97
,, wood . . .	0·50	27	84
Wet asphalt . . .	0·38	21	63
,, macadam . .	0·37	20½	61
,, wood . . .	0·32	18	53
"Greasy" macadam .	0·19	11	32
,, wood . .	0·11	6½	18½
,, asphalt .	0·06	3½	10

How Excessive Camber Causes Skidding.—He stated that he put forward the above figures as a fair comparative statement,

[1] From D. A. Low's "Pocket Book". [2] From Jamieson's "Mechanics".
[3] Is from a special test. [4] Is from Mr. Worby Beaumont.

"so far as present knowledge enables me to assess the various coefficients for rubber upon asphalt, macadam, and wood," and also "that it is hard to say how low the coefficient of friction may fall for the worst conditions of asphalt in London, but Mr. Worby Beaumont informs me that he has found that a very slight push will start a rubber-tyred vehicle upon its sliding career on a gradient of only 4° [1 in 16] when such an asphalt surface is very greasy".

Mr. Shrapnell Smith concluded his admirable paper with a hope that thorough washing of streets would, in great measure, obviate the slipperiness of our streets, and that "street cleansing methods should be revised and brought up to date as the proportion of motor traffic in our great cities becomes higher year by year".

We shall all agree with these concluding remarks, and it is evident that all modern road construction is tending towards the reduction so much as is possible of slipperiness on the surfaces of our roads and streets. Modern "carpets" are less slippery than natural rock asphalt, and both wood pavements and granite setts are now laid with a view to minimise slipperiness, but until the ideal road surface is discovered, the only remedies appear to be—

(*a*) The frequent cleansing, or washing, of the surfaces of the streets.

(*b*) The reduction of excessive camber.

(*c*) The spreading of suitable sand, gravel, grit, or chippings, as occasion demands.

Conclusion.—In conclusion, the author trusts that this book may have added something of interest to the question of roads which has recently so widely developed.

In the past the tendency of local authorities has been to view the question of their roads from a communal rather than a national standpoint. There can be no doubt that the roads of this country will play a very important part in inland transportation; the railways are congested, the canals are only able to deal with very slow traffic, the tramways and light railways, constructed on roads, are destructive to the general traffic and out of date. It is to the roads that we shall have to look for the supply of agricultural products to the consumer; it will be the flexible motor omnibus or Reynard train, and not the rigid tramcar which will take workers to and from their cottage homes to the factory or workshop. It will be by road that the larger shops and stores will deliver goods to their customers. For many years past, transportation has been bound, like Andromeda, to the rock of the railway, but to-day, Perseus, in the form of the self-propelled vehicle, has come to her aid, and by the assistance of Medusa's head, in the guise of good roads, will liberate her from these bonds, and transportation will again be free. It is for the highway engineer to now play his part in this liberation.

APPENDIX I.

CONFERENCE OF ROAD USERS ON TRAFFIC REGULATIONS.

RESOLUTIONS.

(1) That in the opinion of this Conference it is essential that the present rules of the road should be, by statute, rendered obligatory on *every* vehicle using the roads in both town and country.

(2) That when overtaking any carriage, etc., the rule should be to overtake and pass on the "off" or right side.

(3) That the revised rules of the road should contain a provision that all traffic coming from a side road into a main road should give way to traffic on the main road.

(4) That in cases of doubt or difficulty the determination of what is a "main" and a "side" road should rest with the local authority, who should be required to erect and maintain the sign indicating the "side" road.

(5) That in order to promote the safety of pedestrians and minimise the risk of accidents caused by persons stepping off the kerb or path, the rule of the road for pedestrians on the pavements and pathways should be altered to coincide with that for vehicles.

(6) That wherever practicable, and particularly in traffic-congested areas, the slow-moving traffic should keep *close* to the left side of the road.

(7) That the same obligation which is now laid upon motor car drivers by Section 1 of the 1903 Motor Car Act—viz. to have regard "to the amount of traffic which actually is at the time, or which might reasonably be expected to be, on the highway," also to the condition of the traffic—should be imposed by statute upon all drivers and all pedestrians, in order that the existing highways may be used to their full capacity instead of being largely wasted, as is now the case.

(8) That it should be impressed upon drivers and riders of all vehicles, by any means possible, that in passing other vehicles or pedestrians it is essential that they should not cut into the near side of the road too soon; and that in passing and overtaking they should give reasonable room to other vehicles, especially cycles.

(9) That this Conference desires to draw the attention of the authorities to the obstruction of roads by itinerant tradesmen and hawkers, and suggests that steps should be taken to remove what is a nuisance to

pedestrians and a source of inconvenience and occasional danger to the drivers of every class of vehicle.

(10) That any person who obstructs road traffic in any way, or who commits on a highway any act which is likely to cause an accident, or which is calculated to endanger the safety of the public, should be prosecuted and punished.

(11) That this Conference recommends that there should be uniformity in the warning sounds emitted by mechanically propelled vehicles and cycles. For example, that the use of horns and hooters should be restricted to mechanically propelled vehicles and the use of bells to cycles.

(12) That, if possible, the drivers of heavy motors with trailers attached should adopt some contrivance by which they can be made aware of overtaking traffic.

(13) That statutory provision should be made by which the building of hooded vehicles without panels at the sides, as a means of allowing the driver an adequate view on either side, should be prohibited.

(14) That this Conference, having considered the question of cattle straying upon the highways, and in view of the information that the Attorney-General has undertaken to introduce a short Act dealing with the subject, recommends that he be requested to deal with this matter as early as possible.

(15) That this Conference recommends that whenever sheep, cattle, or pigs are driven along the highways after dark, a light should be carried.

(16) That a code of road signals to be used by drivers of all vehicles, mechanically or personally propelled or horse-drawn, be adopted.

(17) That the authorities print and circulate copies of the rules of the road, and that these be issued in such a manner as to secure their reaching the hands of the drivers of all public conveyances, the employees of all trades vehicles, and the licensees of every class of vehicle.

(18) That the rule of the road and of the pavement and pathway be taught in all schools and supplemented by instructions as to how pedestrians should proceed when in traffic-congested areas, and when crossing streets or roads.

(19) That this Conference is in sympathy with the principle of the establishment of a Permanent Central Board of Traffic Control for the Metropolitan area.

(20) That this Conference calls upon the Government to bring pressure on street authorities to induce them to diminish the camber in every case where streets are being re-laid.

(21) That this Conference is of opinion that there should be uniformity in the lighting requirements of vehicles throughout the British Isles.

(22) That in the opinion of this Conference every road vehicle using the road, and however propelled, should display a white light to the front and a red light to the rear.

(23) That this Conference recommends that, as a general rule, the

minimum age for licensees of all kinds of mechanically propelled vehicles be increased to eighteen years, but that the authorities be empowered to issue licences to younger applicants on their being convinced that they are fit and proper persons to hold such licences.

(24) That this Conference strongly maintains that, in future, a standard of physical fitness should be insisted upon before any licence to drive a mechanically propelled vehicle is granted.

(25) That this Conference is of opinion that a uniform system of national warning signs throughout the British Isles is essential, and recommends that Government should specify a standard pattern of warning sign and post to be used solely for traffic regulation purposes; also that these signs and posts should be erected upon a uniform system and that a Central Department should supervise this work, in order to secure such uniformity.

(26) That the system of national warning signs advocated by the Roads Improvement Association and embodied in their Memorandum regarding the same be recommended for adoption.

(27) That in the opinion of this Conference, it is essential that existing Acts of Parliament which deal with the laws relating to the highway be consolidated and brought up to date, and that the rules regarding traffic on the highway should have statutory effect.

(28) That the ultimate results of the deliberations of this Conference be handed in to the Select Committee of the House of Commons on Motor Traffic, and that some one on behalf of this Conference be nominated to appear before the Committee and, if necessary, be examined upon the recommendations adopted by the Conference.

APPENDIX II.

ROYAL AUTOMOBILE CLUB.

Traffic Rules.

The following suggested Traffic Rules are founded: (a) *On the present laws and accepted customs whenever possible.* (b) *As regards Rule* 8, *on the Board of Trade "Regulations for Preventing Collisions at Sea". This is a well-proved rule, and is found to be both simple and efficient in practice. There is at present no rule or custom equivalent to it on the road.* (c) *In a few instances on small changes and additions in cases where experience has shown that the present laws and customs, which were sufficient to deal with the previous traffic, are inadequate to deal with that now using the roads.*

General.

(1) The driver of every vehicle shall be responsible for controlling it adequately under normal conditions of traffic on the highway.

(2) It shall be an offence to obstruct road traffic in any way or to commit on a highway any act which is likely to cause an accident, or which is calculated to endanger the safety of the public.

(3) Every vehicle moving on the highway shall be kept on the left side of the road, but it shall not be deemed an offence to travel on any other part of the road, provided (*a*) that, on the approach from either direction of any other vehicle, the driver shall draw to the left side of the road in such a manner that the approaching or overtaking vehicle is not hindered, and (*b*) that the left side of the road be assumed on approaching a junction with any other road, or when passing over the crests of hills or over bridges with steep inclines or when travelling round a curve which may conceal approaching traffic.

(4) A vehicle shall not overtake another vehicle at a road junction.

(5) (*a*) When one vehicle is overtaking another the overtaking vehicle shall pass the other on the right-hand side.

(*b*) If, however, the overtaken vehicle be in such a position that the overtaking vehicle can, after giving due warning, assume a position on the near side of the former, the onus of keeping clear shall rest with the driver of the overtaken vehicle.

(6) The onus of ascertaining if the road is clear in every direction

shall rest with the driver of any vehicle that alters its speed or direction, unless such alteration is necessary in order to follow the road.

(7) At any road, junction, or crossing where one road is superior to the other—for example, where a smaller road joins or crosses a main road—all traffic emerging from the inferior road shall give way to that upon the superior road.

When a vehicle is about to emerge from a side road, gateway, carriage drive, archway, or similar access, the driver shall first ascertain if the superior road is clear.

If he desires to proceed to the left he may do so, provided (*a*) that his divergence will not inconvenience other traffic, and (*b*) that he is able to keep close to the near side when making the turn. Should traffic be present on the superior road he should turn so that he falls to the rear of such traffic.

If he desires to proceed to the right he may do so, provided that the near side of the road can be taken immediately after the turn has been made.

If he desires to cross the road he may do so, provided he keeps his vehicle clear of any vehicle approaching from the left and crosses to the rear of such vehicle.

(8) Whenever two vehicles converge upon a point, the vehicle which shall give way is the one which has the other on its left side.

(9) Drivers of heavy or slow vehicles shall at all times give way as quickly as possible to drivers of faster vehicles. Provided that drivers of fast or light vehicles shall not endeavour to enforce this rule where such action is likely to cause unnecessary distress to horses or to place any horse or heavy vehicle in jeopardy.

Special Rules for Horse Vehicles.

(10) (*a*) Should a horse-drawn vehicle be left unattended the driver of the vehicle shall be held responsible for any damage that may result.

(*b*) Should a horse be frightened by undue noise upon the highway the onus of any damage resulting shall rest upon the person responsible for the noise.

Pedestrians.

(11) (*a*) Foot passengers shall enjoy equal rights with vehicles to the use of the road and shall be under equal obligations.

(*b*) Where there is no footpath pedestrians shall keep to the right-hand side of the road and as near the side as possible.

Sound Signals.

(12) (*a*) Motor vehicles not authorised to exceed 12 miles per hour shall be provided with a gong of regulation pattern.

(*b*) Motor omnibuses shall be provided with a two-note gong of regulation pattern.

(*c*) Motor cabs shall be provided with a reed horn of regulation pattern.

(*d*) Pedal-driven cycles shall be provided with a bell, and no other sound signal.

(*e*) Only horns or gongs may be used in cities and towns.

Hand Signals.

(13) Before any turning or stopping movement is commenced the driver of every vehicle shall give adequate notice by means of signals as set out hereunder, irrespective of the amount of traffic which may be on the road at the time.

The right hand and arm held out horizontally signify that any vehicle in the rear should keep clear, as the signaller is turning to the right.

The right hand and arm held downwards and swung from rear to front signify that any vehicle in the rear should pass, as the signaller is either slowing or turning to the left.

The right hand and arm held upwards signify that the signaller intends to stop.

In the case of horse vehicles the whip may serve the same purpose as the driver's hand and arm.

Lights.

N.B.—*In the following rules a wide-angle lamp is one having . . .; a narrow-angle lamp is one having . . .*

(14) (*a*) Every vehicle on a highway shall have its presence indicated by means of a light or lights, as hereunder specified, during the period between half an hour after sunset and one hour before sunrise from November 1 to March 31, and between one hour after sunset and one hour before sunrise during the remaining months of the year.

(*b*) Hand carts shall be provided with a lamp showing a white light, which is hung low down and is visible from all sides.

(*c*) Pedal-driven cycles shall be provided with a lamp which shows a white light in the direction in which the machine is travelling and a lamp or "reflex light" showing red from behind.

(*d*) Single-track motor cycles shall carry a suitable form of headlamp, which shall be provided with a green sector in the upper part of the lamp visible in a horizontal direction and also with a small green pane in the right-hand side, and with a lamp or "reflex light" showing red from behind.

(*e*) Horse-drawn vehicles shall exhibit a white wide-angle lamp on the extreme right or off side of such vehicle and as near the front thereof as may be convenient, and also a white wide-angle lamp on the near side, and at the rear and as near the off side as possible a lamp or "reflex light" showing red from behind.

(*f*) Vehicles carrying loads which overhang the rear by more than four feet or which project beyond the side shall, in addition to the other lights, carry aswinging lantern at or near the extreme end of the overhang.

(*g*) Traction engines and other motor vehicles not authorised to exceed 12 miles per hour shall, in addition to the two white wide-angle lamps and the red tail lamp, carry a white narrow-angle lamp at a point 18 inches above the level of the two white wide-angle lamps and midway between them.

(*h*) Every trailer shall show a white wide-angle lamp on the off side, whilst the last trailer shall also exhibit a lamp or "reflex light" showing red from behind.

(*j*) Motor vehicles authorised to exceed 12 miles per hour shall exhibit two narrow-angle lamps in front, the off-side one showing green and the near-side one showing white, and also a lamp or "reflex light" showing red from behind. Headlamps are optional, but in all cases the side lights must be shown.

(*k*) A horse-drawn vehicle laden with straw, hay, or any inflammable material, and proceeding at a walking pace, is exempt from the ordinary rules for lights, but the driver shall carry a lantern, and the onus shall rest with the driver to make its light visible to the driver of any other approaching or overtaking vehicle.

(*l*) During harvest time it shall not be compulsory for vehicles engaged on harvest operations and proceeding from one part of a farm to another to exhibit lights, but in the case of such a vehicle travelling without a light no claim by its owner shall lie in respect of damages that may be sustained arising from the absence of lights, provided that the rule of the road has otherwise been adhered to.

(*m*) During the hours of darkness no vehicle shall be left on the high road without lights, and, except in illuminated streets, no vehicle shall be left standing on the highway except with the near side of the vehicle against the kerb or edge of the roadway.

INDEX.

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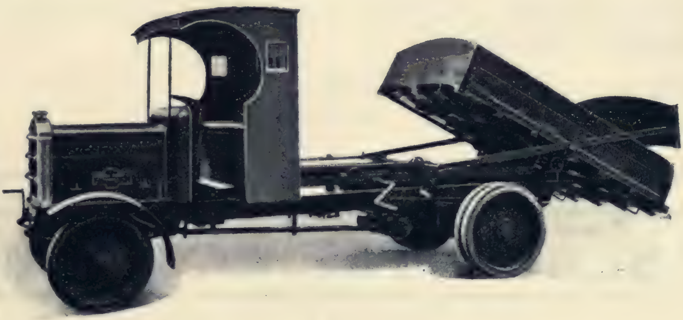

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